Bacteria TMDLs for Abrams Creek and Upper and Lower Opequon Creek Located in Frederick and Clarke County, Virginia

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

A part of the Potomac River basin (USGS Hydrologic Unit Code 020700), Opequon Creek is a tributary of the Potomac River, which empties into the Chesapeake Bay. Abrams Creek is a tributary of Opequon Creek. For clarity, the two impaired segments of Opequon Creek were designated “Upper” and “Lower.” The headwaters of Upper Opequon Creek (Segment ID VAV-B08R_OPE01A00) lie to the southwest of the City of Winchester. Abrams Creek (Segment ID VAV-B09R_ABR01A00) (which runs through the city of Winchester) empties into Opequon Creek. Lower Opequon Creek (Segment ID VAV-B09R_OPE01A00) begins at the confluence of Abrams Creek and Upper Opequon Creek and ends at the point where the Opequon crosses the Virginia/West Virginia state line.

The Abrams Creek watershed is located in Frederick County, VA, surrounding the city of Winchester. The watershed is 12,285 acres in size. Abrams Creek is mainly an urban watershed (about 50%). The majority of the remaining 50% of the watershed area is divided between forest and agriculture, 22 and 27% respectively. Abrams Creek flows east and discharges into Opequon Creek.

The Virginia Department of Conservation and Recreation (VADCR) has assessed the Abrams Creek watershed as having a high potential for nonpoint source pollution from urban sources. Virginia DEQ personnel monitored pollutant concentrations at the Abrams Creek watershed outlet (Station ID No. 1AABR000.78) on a monthly basis over 27 years (1976-2003). Of the 58 water quality samples collected from July 1992 through June 1997 (the 1998 303d 5–yr listing period) at the outlet of the watershed, 17% of the samples exceeded the instantaneous standard. The instantaneous standard specifies that fecal coliform concentration in the stream water shall not exceed 1,000 colony forming units (cfu) per 100 mL (1,000 cfu/100 mL). Consequently, this segment of Abrams Creek was assessed as not supporting the Clean Water Act’s Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a,b). The impairment starts at the headwaters and continues downstream to its confluence with Opequon Creek, for a total of 10.8 stream miles.

The Upper Opequon Creek watershed is located in Frederick and Clarke Counties, Virginia, and lies primarily to the south of the city of Winchester. The watershed is 36,905 acres in size. The Upper Opequon is mainly an agricultural watershed (about 50%) and is characterized by a rolling valley. The majority of the remainder of the watershed area is divided between forest (33%) and urban land uses (14%). The Upper Opequon flows east and northeast, discharging into the Lower Opequon.

The VADCR has assessed the Upper Opequon watershed as having a high potential for nonpoint source pollution from agricultural sources. Virginia DEQ personnel monitored pollutant concentrations at the Upper Opequon watershed outlet (Station ID No. 1AOPE036.13) on a monthly basis over 12 years (1991-2003). Of the 58 water quality samples collected from July 1992 through June 1997 at the outlet of the watershed, 19% of the samples exceeded the instantaneous standard of 1,000 cfu/100 mL. Consequently, this segment of Upper Opequon Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b). Given that water samples were collected on a monthly basis, the geometric mean criterion could not be calculated. The impairment starts at the headwaters and continues downstream to its confluence with Abrams Creek, for a total of 24.88 stream miles.

The Lower Opequon watershed is located in Frederick and Clarke Counties, Virginia, and lies primarily to the northeast of the city of Winchester. The watershed is 52,873 acres in size and includes the Abrams Creek watershed. The Lower Opequon is mainly an agricultural watershed (about 50%) and is characterized by a rolling valley. The majority of the remainder of the watershed area is divided between forest (29%) and urban land uses (19%).

The VADCR has assessed the Lower Opequon watershed as having a high potential for nonpoint source pollution from agricultural sources. Virginia DEQ personnel monitored pollutant concentrations near the Lower Opequon watershed outlet (Station ID No. 1AOPE025.10) on a monthly basis over 22 years (1979-2001). Of the 59 water quality samples collected from July 1992 through June 1997 at this station, 12% of the samples exceeded the instantaneous standard of 1,000 cfu/100 mL. Consequently, the Lower Opequon Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b). Given that water samples were collected on a monthly basis, the geometric mean criterion could not be calculated. The impairment is delineated on a stream length of 8.82 miles, beginning at its confluence with Abrams Creek and continuing downstream to the Virginia/West Virginia state line.

In order to remedy the water quality impairment pertaining to fecal coliform, a Total Maximum Daily Load (TMDL) has been developed, taking into account all sources of bacteria and a margin of safety (MOS). The TMDL was developed for the new water quality standard for bacteria, which states that the calendar-month geometric mean concentration of *E. coli* shall not exceed 126 cfu/100 mL, and that no single sample can exceed a concentration of 235 cfu/100mL. A glossary of terms used in the development of this TMDL is listed in Appendix A.

1.2. Sources of Fecal coliform

There are two significant point sources and 43 smaller sources permitted to discharge fecal coliform in the Abrams Creek and Upper and Lower Opequon Creek watersheds; however, the majority of fecal coliform load originates from nonpoint sources. Nonpoint sources of fecal coliform in the two Opequon Creek watersheds are primarily agricultural (land-applied animal waste and manure deposited directly on pastures by livestock), with a significant fecal coliform load due to cattle directly depositing manure in streams. In the Abrams Creek watershed, the predominant nonpoint sources include fecal coliform deposited directly on pastures (primarily livestock) and on those land uses grouped under the residential land use category (primarily pets and wildlife). Wildlife contributes to fecal coliform loadings on all land uses, according to the acceptable habitat range for each species. Non-agricultural nonpoint sources of fecal coliform loadings include failing septic systems and pet waste. The amounts of fecal coliform produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in wildlife habitat and livestock production and practices. Livestock management and production factors, such as the fraction of time cattle spend in confinement or in streams and the amount of manure storage and spreading schedules, were considered on a monthly basis.

1.3. Modeling

The Hydrologic Simulation Program – FORTRAN (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Abrams Creek, Upper Opequon, and Lower Opequon watersheds. To identify localized sources of fecal coliform within each watershed, the Abrams Creek watershed was divided into eleven sub-watersheds, the Upper Opequon Creek watershed was divided into sixteen sub-watersheds, and the Lower Opequon Creek watershed was divided into fifteen sub-watersheds. These subdivisions were based primarily on homogeneity of land use. The Lower Opequon watershed includes the Abrams Creek watershed (sub-watershed B09-15). While Abrams Creek is part of the Lower Opequon, the Virginia Department of Environmental Quality (VADEQ) required that a separate TMDL be developed for Abrams Creek. The TMDL loads for Abrams Creek and Upper Opequon Creek were considered when developing the Lower Opequon Creek TMDL.

The hydrology component of HSPF was calibrated and validated for Abrams Creek and Upper Opequon Creek. Lower Opequon Creek is not gaged at the Virginia/West Virginia state line; as result, Lower Opequon Creek was not calibrated for hydrology. While the Lower Opequon Creek sub-watershed B09-15 (Abrams Creek) is highly urbanized, the remaining portion of the Lower Opequon Creek watershed (14 sub-watersheds) is primarily rural and has a land use distribution comparable to the Upper Opequon Creek watershed. Because Lower Opequon Creek is ungaged, the decision was made to model the remaining 14 sub-watersheds of the Lower Opequon (hereafter referred to as the Lower Opequon watershed remnant) using the hydrology model calibrated for the Upper Opequon. The water quality component was calibrated for all three watersheds using fecal coliform data collected by VADEQ.

The hydrology component of HSPF was calibrated for Abrams Creek and Upper Opequon Creek using data from a 3-year and 5-year period, respectively. The calibration periods covered a wide range of hydrologic conditions, including low- and high-flow conditions, as well as seasonal variations. The calibrated HSPF data set was validated on a separate period of record for Abrams Creek (6 years) and Upper Opequon Creek (5 years). The calibrated HSPF model adequately simulated the hydrology of the Abrams Creek and the Upper Opequon Creek watersheds.

The water quality component of the HSPF model was calibrated using the fecal coliform data specific to each watershed for the 5-year listing period. Inputs to the model included fecal coliform loadings on land and in the stream and simulated flow data. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate and transport of fecal coliform in the watershed.

All three of these watersheds are experiencing urban development and growth, which must be accounted for in the TMDL development process (modeling). Future land use scenarios were created based on the following assumptions:

- Future urban development would occur within Frederick County's "Urban Development Areas" (UDAs) and "Commercial Centers" (ComCntrs);
- Agricultural and forestry land uses within these areas would decrease to 0% under full build-out;
- Water, transitional, and urban greenspace areas would remain the same;
- Commercial and residential land uses within these areas would increase in proportion to their existing ratios for UDAs; land use in ComCntrs would increase only in the commercial land use category.

Three future land use scenarios were created based on 25%, 50%, and 100% build-out within the UDAs and ComCntrs within Frederick County. Based upon experience with the rate of development in similarly urbanizing areas, the decision was made to develop the TMDL modeling scenarios assuming an anticipated 25% build-out within the UDAs and ComCntr planning zones in the Opequon Creek watershed. The reductions required to meet TMDL allocations, therefore, will be based on projected *E. coli* loads resulting from future land use distributions corresponding to the 25% build-out scenario.

1.3.1. Margin of Safety

A margin of safety (MOS) is included to account for any uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (USEPA, 1991). For the Abrams, Upper Opequon, and Lower Opequon Creek TMDLs, the MOS was implicitly incorporated into each TMDL by conservatively estimating several factors affecting bacteria loadings, such as animal numbers, production rates, and contributions to streams.

1.3.2. TMDL Allocations and Stage 1 Implementation

Based on amounts of fecal coliform produced in different locations, monthly fecal coliform loadings to different land use categories were calculated for each sub-watershed in each watershed for input into the model. Fecal coliform content of stored waste was adjusted to account for die-off during storage prior to land application. Similarly, fecal coliform die-off on land was taken into account, as was the reduction in fecal coliform available for surface wash-off due to incorporation following waste application on cropland. Direct seasonal fecal coliform loadings to streams by cattle were calculated for pastures adjacent to streams. Fecal coliform loadings to streams and land by wildlife were estimated for several species. Fecal coliform loadings to land from failing septic systems were estimated based on number and age of houses. Fecal coliform contribution from pet waste was also considered.

For the allocation scenarios, a target of 0% violations of both the instantaneous and geometric mean water quality standards was used. For the Stage 1 implementation scenario, a target of 0% reductions in wildlife and 10% violation of the instantaneous standard was used.

1.3.2.a. Abrams Creek TMDL

Existing Conditions

Contributions from various sources were represented in HSPF to establish the existing conditions for the representative period of 5 years (June 1992 through June 1997). The visual assessment of the simulated and actual values indicated a good agreement between the two. Nonpoint-source (NPS) loadings from impervious land segments (ILS) are the largest source of *E. coli* in the stream, accounting for almost 80% of the mean daily *E. coli* concentration. Loading from upland pervious land segments (PLS) is responsible for almost 4% of the mean daily *E. coli* concentration. While direct deposits to streams by cattle and wildlife are responsible for only 16.4% of the mean daily *E. coli* concentration, these sources can have a significant impact on water quality at any given time because fecal material is deposited directly in the stream and is not subject to die-off during transport as are land applied sources. During the summer when stream flow was lower, cattle spent more time in streams, and thereby, increased direct fecal coliform deposition to streams when water for dilution was least available.

Allocation Scenarios

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero violations. The scenarios are presented in Table 1.1.

Table 1.1. Bacteria allocation scenarios for Abrams Creek watershed, using 25% build out scenario.

Scenario Number	% Violation of *E. coli* Standard		Percent Reductions to Fecal Coliform Loading from Abrams Creek Modeled Source Categories, %							
	Geometric mean	Instantaneous	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	All ILS	Forest PLS	Residential PLS
Existing Conditions	4	12	0	0	0	0	0	0	0	0
01	2	12	0	50	50	50	0	0	50	50
02	0	0	0	0	0	0	0	100	0	0
03	0	0	0	0	0	0	0	97	0	97
04	0	0.03	40	0	0	0	0	95	0	95
05	0	0	30	0	0	0	0	96	0	96

In scenario 01, contributions from pervious land segments (PLSs) were reduced by 50% and little change was seen in the violations of the standards. In scenarios 02 and 03, ILS contributions were nearly and completely eliminated, which met the requirements of the standard. Because of this and the results of scenario 01, it was concluded that reductions in bacteria coming from agricultural and forestland PLSs would not be necessary to meet the standards. Several scenarios were evaluated to investigate what other source reductions could be combined with the ILS reductions such that 100% reductions would not be required from ILS areas. The fact that no reductions are required from PLS sources is consistent with the character of the Abrams Creek watershed: it is highly urbanized with few livestock. Reductions in wildlife were considered to be impractical to implement. Therefore, reductions from Cattle DD were considered (Scenarios 04 and 05). Scenario 04 reduced instantaneous standard violations to 0.03% with Cattle DD reductions of 40%. Scenario 05 was then considered, with Cattle DD reductions of 30% and 96% reductions in ILS and Residential PLS areas, and succeeded in meeting the standards with no violations. Scenario 05 shown in Table 1.1 was selected as the TMDL build-out allocation for the 25% build-out projection because it required a low reduction from Cattle DD and a less than 100% reduction from ILS and Residential PLS sources. This scenario calls for reductions in Cattle DD of 30% and loading from ILS sources of 96%. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 1.1 for the TMDL allocation (Scenario 05), along with the standards.

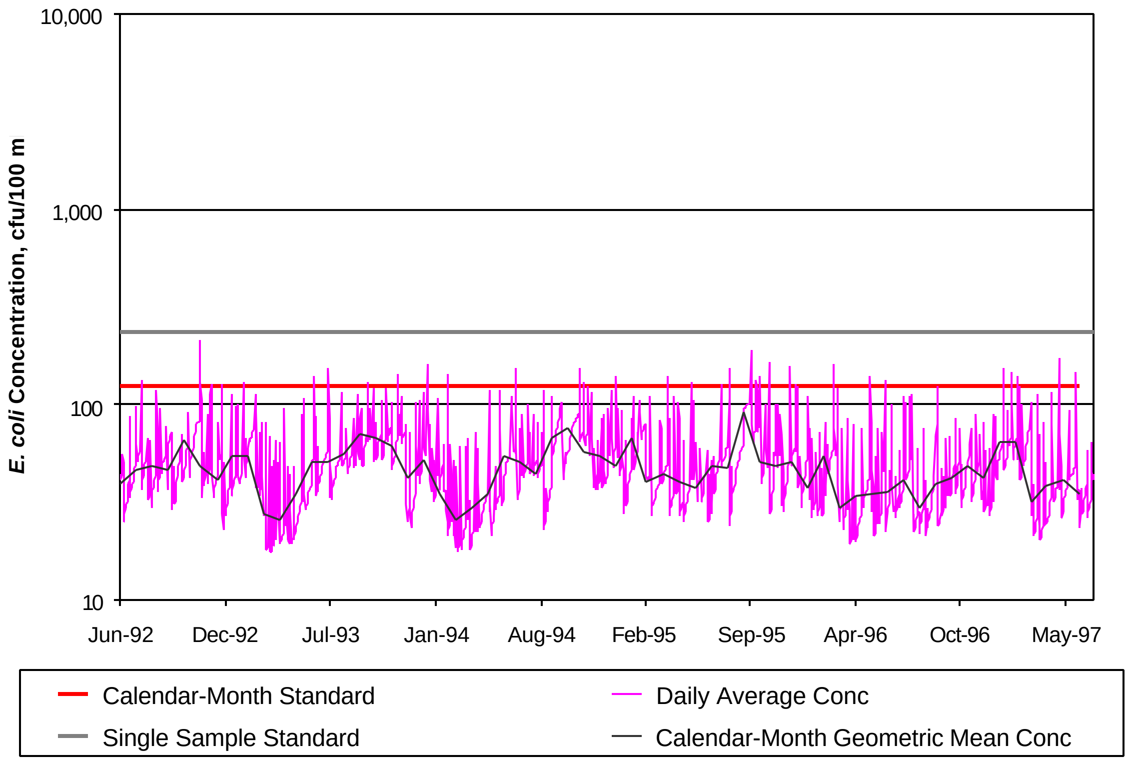

Figure 1.1. Calendar-month geometric mean standard, single sample standard, and successful E. coli TMDL allocation for 25% build-out (Allocation Scenario 05 from Table 1.1) for Abrams Creek.

Because the portions of the Abrams Creek watershed that lie within the City of Winchester are covered by one of two MS4 permits, the assumption was made that the *E. coli* load originating on the portion of the impervious land segments covered by the MS4 permits (ILS MS4 Load) will be controlled by those permits. The difference between the ILS MS4 waste load allocation and the 25% build-out load is $465.6\text{x}10^{12}$ cfu/yr ($485 \text{ x}10^{12} - 19.4 \text{ x}10^{12} = 465.6 \text{ x}10^{12}$), which is to be mitigated by MS4 regulation requiring implementation of best management practices to reduce pollutants to the "maximum extent practicable." The annual fecal coliform loads for the existing and future land-use projection, as well as the TMDL allocation loads for the fecal coliform source categories are shown in Table 1.2.

Table 1.2. Annual fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 05).

	Existing Condition Load ($\times 10^{12}$ cfu)	**25% Build-out Load** ($\times 10^{12}$ cfu)	**TMDL Allocation Scenario (04) % Reduction**	**Future TMDL Allocation** ($\times 10^{12}$ cfu)
Cattle DD	4.1	4.1	30	2.9
Wildlife DD	12.7	12.5	0	12.5
All PLS	8,810	9,110	0	9,110
ILS non-MS4	257.0	333.0	96	13.3
ILS MS4[a]	451.0	485.0	96	19.4
Total	9,530	9,940	8[b]	9,160

[a]Although a NPS loading, the allocation for this sources is included in WLA of TMDL calculation.
[b]Total percent reduction includes the 465.6×10^{12} load assumed to be mitigated by MS4 regulation in the Abrams Creek watershed for the City of Winchester (VAR040053) and VDOT-Winchester Urban Area (VAR040032).

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 30% reduction in direct deposits of cattle manure to streams and a 96% reduction in nonpoint source loadings to impervious land surfaces outside of the MS4 regulated areas, and effectively a 96% reduction of source loadings to impervious land surfaces with the MS4 regulated areas, which it is assumed will be achieved though the MS4 process. Although not estimated by our process, should any straight pipes be found during implementation, 100% of them should be removed. Using Eq. [6.1], the summary of the bacteria TMDL for Abrams Creek for the selected allocation scenario (Scenario 04) is given in Table 1.3. The TMDL load was determined as the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario. In Table 1.3 below, the WLA was determined by isolating the contributions from MS4 areas to the *E. coli* output from the HSPF model. The LA is then determined as the TMDL – WLA.

$$\text{TMDL} = \text{SWLA} + \text{SLA} + \text{MOS} \qquad [1.1]$$

where,

WLA = wasteload allocation (point source contributions);
LA = load allocation (nonpoint source contributions); and
MOS = margin of safety, implicit.

Table 1.3. Average annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Abrams Creek bacteria TMDL.

Pollutant	SWLA	SLA	MOS	TMDL
E. coli	310×10^{10} (VAR040053 and VAR040032)	$1{,}650 \times 10^{10}$	NA	$1{,}960 \times 10^{10}$

NA – Not Applicable because MOS was implicit

Stage 1 Implementation

An alternative scenario was evaluated to establish goals for the first stage of the implementation of the TMDL. The implementation of such a transitional scenario, or Stage 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through continued data collection. Stage 1 implementation requires a 20% reduction in direct loading by cattle in-stream and a 60% reduction in loading from ILSs. As previously discussed, the reduction in ILS loadings will largely be accomplished through the MS4 regulatory framework.

1.3.2.b. Upper Opequon Creek TMDL

Existing Conditions

Contributions from various sources were represented in HSPF to establish the existing conditions for the representative period of 5 years (September 1992 through September 1997). The visual assessment of the simulated and actual values indicated a good agreement between the two. Contributions from cattle and wildlife directly depositing feces into the stream make up over 40% of in-stream *E. coli* concentrations. The significant contributions from these sources dictated that reductions in both cattle and wildlife direct deposit loadings were required in the TMDL allocation. Contributions from pervious land segments also weigh in heavily at 50% of the in-stream concentrations. Contributions from impervious land surfaces are not significant in the watershed.

Allocation Scenarios

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero violations. The scenarios are presented in Table 1.4.

Table 1.4. Bacteria allocation scenarios for Upper Opequon watershed, using 25% build out scenario.

Scenario Number	% Violation of *E. coli* Standard		Percent Reductions to Fecal Coliform Loading from Upper Opequon Modeled Source Categories, %							
	Geometric mean	Instantaneous	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	All ILS	Forest PLS	All Residential PLS
Existing Conditions	61	43	0	0	0	0	0	0	0	0
01	44	37	50	50	50	50	50	50	50	50
02	0	0.2	100	100	100	100	0	100	0	100
03	0	0.2	99	95	95	100	99	95	0	95
04	0	0	100	95	95	100	99	95	0	95
05	0	0.1	100	90	90	100	90	90	0	90
06	0	0	100	90	90	100	95	90	0	90

In scenario 01, all contributions were reduced by 50%. This scenario reduced, but did not eliminate violations of either the geometric mean or instantaneous standard. Scenario 02 was examined to evaluate the impact of eliminating all fecal coliform sources, except wildlife. Violations of the instantaneous standard (0.2%) persisted. As discussed in the previous section, and shown in Figure 6.4, Cattle DD is a significant source in the Upper Opequon creek watershed, and as a result significant reductions from this source are necessary. In Scenario 03, contributions from both Cattle DD and Wildlife DD are both reduced by 99%. Additionally, contributions from PLS and ILS sources (except forest) are reduced by 95%. Even under this significant reduction scenario, minor but persistent standards violations occurred (instantaneous, 0.2%). In Scenario 04 Cattle DD contributions were eliminated. Although no violations occurred, the scenario was unnecessarily stringent, and therefore some further scenarios were evaluated. In particular, the wildlife reductions were too high. In Scenario 05, Wildlife DD and Cropland, Pasture, Residential PLS, and ILS contributions were set to 90%, resulting in a small violation of the instantaneous standard. Because these violations came primarily from direct deposit sources, Scenario 06 was evaluated, in which the wildlife reductions were increased to 95. Scenario 06 produced no standard violations, and was selected at the final TMDL for the 25% build-out projection of

Upper Opequon Creek. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 1.2 for the TMDL allocation (Scenario 06), along with the standards.

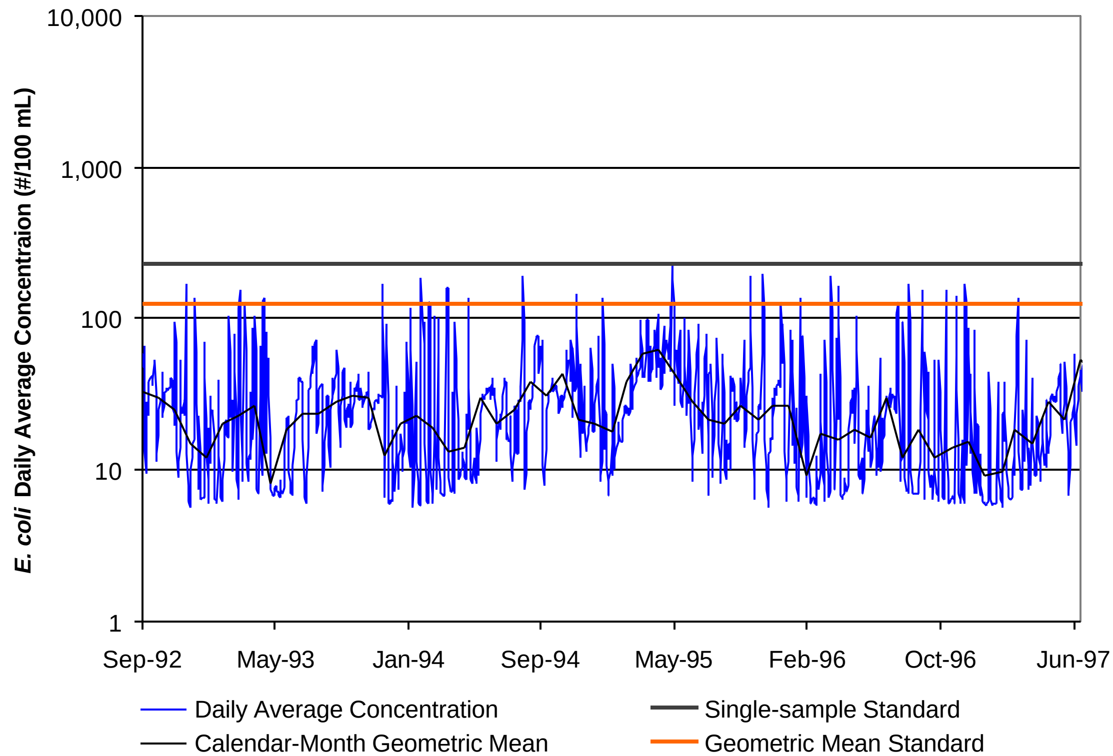

Figure 1.2. Calendar-month geometric mean standard, single sample standard, and successful E. coli TMDL allocation for 25% build-out (Allocation Scenario 06 from Table 1.4) for Upper Opequon.

The annual fecal coliform loads for the existing and future land-use projection, as well as the TMDL allocation loads for the fecal coliform source categories are shown in Table 1.5 for the Upper Opequon Creek watershed.

Table 1.5. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 06).

	Existing Condition Load ($\times 10^{12}$ cfu)	**25% Build-out Load** ($\times 10^{12}$ cfu)	**TMDL Allocation Scenario (06) % Reduction**	**Future TMDL Allocation** ($\times 10^{12}$ cfu)
Cattle DD	93.6	93.6	100	0.0

Wildlife DD	13.2	12.8	95	0.64
All PLS	17,130	16,570	87	2,182
All ILS	4.7	7.0	90	0.7
Point Sources	5.6	5.6	--	5.6
Total	18,076	16,689	87	2,188.9

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 100% reduction in direct deposits of feces by cattle to streams, a 95% reduction in direct deposits of feces by wildlife to streams, and a 90% reduction in nonpoint source loadings to impervious (ILS) and pervious (PLS) land surfaces, except forest. Using Eq. [1.1], the summary of the bacteria TMDL for Upper Opequon Creek for the selected allocation scenario (Scenario 06) is given in Table 1.6. The TMDL load was determined as the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario. In Table 1.6 below, the WLA was obtained by summing the products of each permitted point source's *E. coli* discharge concentration and allowable annual discharge. The LA is then determined as the TMDL – WLA.

Table 1.6. Average annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Upper Opequon bacteria TMDL.

Pollutant	SWLA	SLA	MOS	TMDL
E. coli	357.7×10^{10} 17 1000 gpd units; VA0075191; VA0088722	$3{,}636.7 \times 10^{10}$	NA	$3{,}994.4 \times 10^{10}$

NA – Not Applicable because MOS was implicit

Stage 1 Implementation

An alternative scenario was evaluated to establish goals for the first stage of the implementation of the TMDL. The implementation of such a transitional scenario, or Stage 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through continued data collection. Stage 1 implementation requires a 87% reduction in direct loading by cattle in streams, the elimination of any loading from loafing lots, and an 80% reduction in loading from all PLSs and ILSs, except the forest PLSs. No reductions from wildlife direct deposit are called for.

1.3.2.c. Lower Opequon Creek TMDL

Existing Conditions

Contributions from various sources were represented in HSPF to establish the existing conditions for the representative period of 5 years (September 1992 through June 1997). The visual assessment of the simulated and actual values indicated a good agreement between the two. Non-point source (NPS) loadings from PLSs are the largest source of *E. coli* in the stream, accounting for 70% of the mean daily *E. coli* concentration. The next largest contributors are loadings from point sources and from Upper Opequon Creek and Abrams Creek. See the corresponding sections for those watersheds for the breakdown of *E. coli* sources for these inputs; they account for almost 8% of the *E. coli* concentration at the watershed outlet. Combined direct deposits to streams by cattle and wildlife are responsible for only 12.5% of the mean daily *E. coli* concentration; typically these sources can have a significant impact on water quality at any given time because fecal material is deposited directly in the stream and is not subject to die-off during transport as are land applied sources. Most cattle in the watershed are already fenced out of the stream, which is why the contribution from livestock to the overall total is so low.

Allocation Scenarios

A variety of allocation scenarios were considered to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the instantaneous limit of 235 cfu/100mL for the 25% build-out scenario. The scenarios and results are summarized in Table 1.7.

Table 1.7. Bacteria allocation scenarios for Lower Opequon watershed, using 25% build out scenario.

	% Violation of *E. coli* Standard		Percent Reductions to Fecal Coliform Loading from Lower Opequon Modeled Source Categories, %							
Scenario Number	**Geometric mean**	**Instantaneous**	**Cattle DD**	**Cropland**	**Pasture**	**Loafing Lot**	**Wildlife DD**	**All ILS**	**Forest PLS**	**All Residential PLS**
Existing conditions + ABR and Upper OPE reductions	2.1	9.7	0	0	0	0	0	0	0	0
01	0	9.6	90	0	0	0	0	0	0	0
02	0	2.2	0	80	80	100	0	25	0	75

03	0	0.1	75	95	95	100	75	70	0	70
04	0	0.2	0	95	95	100	0	70	0	70
05	0	0	0	95	95	100	0	80	0	80

The initial scenario in Table 1.7 reflects the violations that occur if the reductions from the Abrams Creek and Upper Opequon Creek allocation scenarios are used in generating the point source input from these two sources for the model. Scenario 01 calls for a 90% reduction from cattle, but elicits an almost unnoticeable change in violations of the instantaneous standard. Therefore, reductions from cattle were deemed not to be necessary for the final TMDL allocation. This reflects the fact that many farmers in the Lower Opequon Creek watershed remnant have already fenced their cows out of the stream. Scenarios 02-05 took incremental reductions in the PLS and ILS sources to determine the minimum reductions necessary to meet water quality standards. Comparison of scenarios 03 and 04 shows that direct contributions from wildlife sources are also not significant contributors to the *E. coli* concentrations in the watershed remnant. The final scenario shown in Table 1.7, Scenario 05, was selected as the TMDL build-out allocation for the 25% build-out projection because it met the water quality standards while requiring the fewest reductions from the nonpoint sources. This scenario calls for reductions in PLS loadings of 95% for cropland and pastures and 100% for loafing lots. The scenario also calls for a reduction in loading from ILS sources and residential PLS sources of 80%. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 1.3 for the TMDL allocation (Scenario 06), along with the standards.

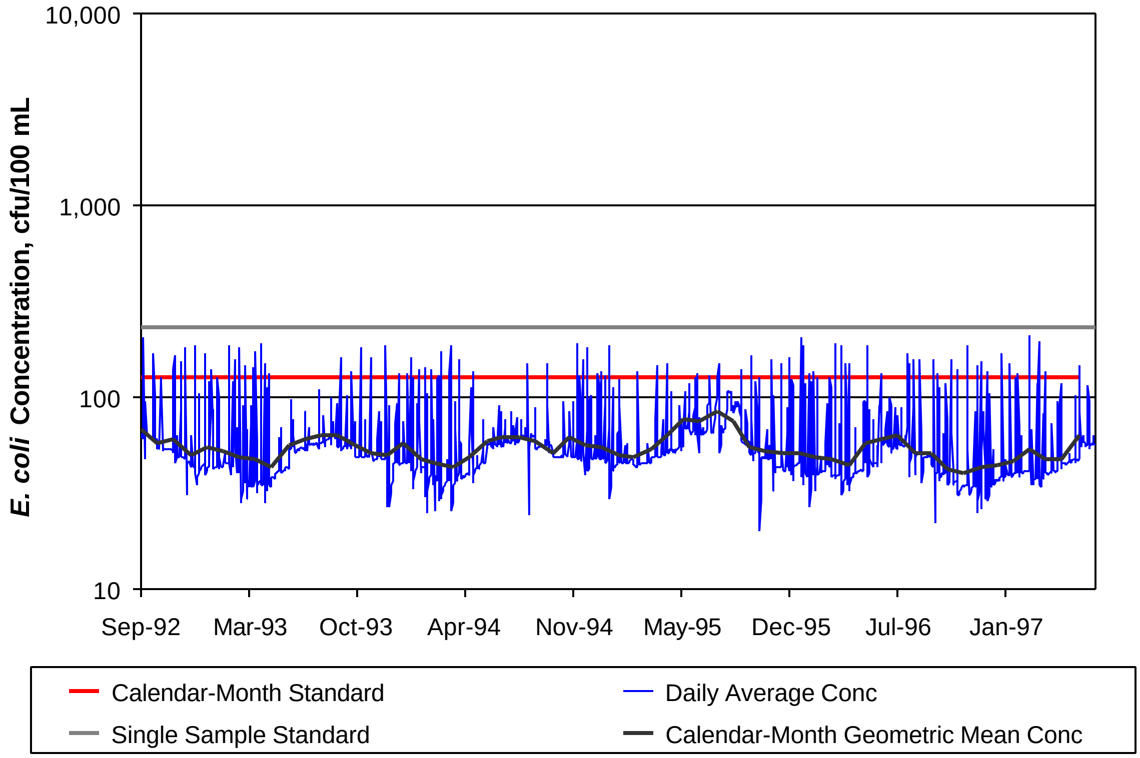

Figure 1.3. Calendar-month geometric mean standard, single sample standard, and successful E. coli TMDL allocation for 25% build-out (Allocation Scenario 05 from Table 1.7) for Lower Opequon.

The annual fecal coliform loads for the existing and future land-use projection, as well as the TMDL allocation loads for the fecal coliform source categories are shown in Table 1.8 for the Lower Opequon Creek watershed.

Table 1.8. Annual fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 06).

	Existing Condition Load (× 10^{12} cfu)	**25% Build-out Load** (× 10^{12} cfu)	**TMDL Allocation Scenario (06) % Reduction**	**Future TMDL Allocation** (× 10^{12} cfu)
Cattle DD	16.2	16.2	0	16.2
Wildlife DD	1.8	1.7	0	1.7
All PLS	24,400	24,500	91.4	2,110
All ILS	3.90	6.55	70.0	1.97
Point Sources	33.8	33.8	--	33.8
Total	24,456	24,558	91.2	2,164

The selected bacteria TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 95% reduction in contributions from cropland and pastures, a 100% reduction in contributions from loafing lots, and an 80% reduction in nonpoint source loadings to impervious land surfaces and residential PLSs. Using Eq. [1.1], the summary of the bacteria TMDL for Lower Opequon for the selected allocation scenario (Scenario 05) is given in Table 1.9. The TMDL load was determined as the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario. In Table 1.9 below, the WLA was obtained by summing the products of each permitted point source's *E. coli* discharge concentration and allowable annual discharge. The LA is then determined as the TMDL – WLA. The TMDL for the remnant reflects only the allocated generation in the Lower Opequon watershed remnant, not including the Abrams Creek watershed (see Section 1.3.2.a for details on Abrams Creek).

Table 1.9. Average annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Lower Opequon bacteria TMDL.

	Pollutant	SWLA	SLA	MOS	TMDL
Lower Opequon Remnant	*E. coli*	$213.0x10^{11}$ 26 1000 gpd units; VA0065552; VA0023116	$948.1x10^{11}$	NA	$1,161.1x10^{11}$

NA – Not Applicable because MOS was implicit

Stage 1 Implementation

An alternative scenario was evaluated to establish goals for the first stage of the implementation of the TMDL. The implementation of such a transitional scenario, or Stage 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through continued data collection. Stage 1 implementation requires no reduction in direct loading by cattle in-stream (most of the cattle in the Lower Opequon Creek watershed presently do not have direct access to the stream), a 100% reduction in loading from loafing lots, a 50% reduction in loading from cropland and pasture PLSs, and a 40% reduction in loading from ILSs and residential PLSs.

1.4. Reasonable Assurance of Implementation

Continued biological and chemical monitoring in the watershed by VADEQ, provisions of Virginia's WQMIRA legislation requiring implementation of developed TMDLs, MS4 regulations on storm sewer discharges, and the potential of funding through Section 319 and USDA's CREP programs all provide the basis for a reasonable assurance that the anthropogenic load reductions will be implemented.

1.5. Public Participation

Public participation was elicited at every stage of the TMDL development process in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In February 2003, members of the Virginia Tech TMDL group traveled to Frederick County to become acquainted with Abrams Creek watershed. The Virginia Tech TMDL group also traveled to Fredrick and Clarke Counties in March of 2003 to become acquainted with Upper and Lower Opequon watersheds. During those trips, the members of the group spoke with various stakeholders. In addition, personnel from Virginia Tech, the Lord Fairfax Soil and Water Conservation District (SWCD), and the Natural Resource Conservation Service (NRCS) visited some watershed residents and contacted others via telephone, and met with Winchester City officials to acquire their input and collect additional information. The first public meeting for Abrams Creek was held on March 13, 2003, at Shenandoah University in Winchester, VA, to inform the stakeholders about the TMDL development process and to obtain feedback on animal numbers in the watershed and fecal production estimates. Approximately 45 stakeholders attended this meeting.

The first public meeting to discuss the impairments of the Upper and Lower Opequon Creeks was held on April 3, 2003, at Shenandoah University in Winchester, VA, to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers and fecal coliform production estimates in the watershed. Approximately 45 stakeholders attended this meeting. After consulting with DEQ, the decision was made to separate the TMDL reports on Abrams Creek and the Upper and Lower Opequon into two reports: one to address the benthic impairments on Abrams Creek and Lower Opequon and the other to address the bacteria impairment on Abrams Creek and the Upper and Lower Opequon. As a result, the final public meeting for the bacteria impairment included all three watersheds. The final public meeting to discuss the bacteria impairments was held on July 8, 2003 at

Shenandoah University in Winchester, VA to present the draft TMDL report and solicit comments from stakeholders. Approximately 11 people attended the final meeting.

CHAPTER 2: INTRODUCTION

2.1. Background

2.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

2.1.2. Impairment Listing

Abrams Creek, Upper Opequon Creek, and Lower Opequon Creek are listed as impaired streams on Virginia's 1998 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to water quality violations of the bacteria standard. The Virginia Department of Environmental Quality (VADEQ) has delineated the Abrams Creek impairment on a stream length of 10.8 miles, beginning at its headwaters and continuing downstream to its confluence with Opequon Creek. Abrams Creek is targeted for TMDL development and completion by 2004. The VADEQ has delineated the Upper Opequon Creek impairment on a stream length of 24.88 miles, beginning at its headwaters and ending at the confluence with Abrams Creek. The Lower Opequon impairment is delineated on a stream length of 8.82 miles, beginning at its confluence with Abrams Creek and continuing downstream to the Virginia/West Virginia state line. The Upper and Lower Opequon are targeted for TMDL development and completion by 2010.

2.1.3. Watershed Location and Description

2.1.3.a. Abrams Creek

A part of the Potomac River basin, Abrams Creek watershed (Segment ID VAV-B09R_ABR01A00) is located in Frederick County, VA, surrounding the city of Winchester

(Figure 2.1). The watershed is 12,285 acres in size. Abrams Creek is mainly an urban watershed (about 50%). The majority of the remaining 50% of the watershed area is divided between forest and agriculture, 22 and 27% respectively. Abrams Creek flows east and discharges into Opequon Creek. Opequon Creek is a tributary of the Potomac River (USGS Hydrologic Unit Code 020700). The Potomac River discharges into the Chesapeake Bay.

2.1.3.b. Upper Opequon

A part of the Potomac River basin, Upper Opequon Creek watershed (Segment ID VAV-B08R_OPE01A00) is located in Frederick and Clarke Counties, Virginia, surrounding the city of Winchester (Figure 2.2). The watershed is 36,905 acres in size. The Upper Opequon is mainly an agricultural watershed (about 50%) and is characterized by a rolling valley. The majority of the remainder of the watershed area is divided between forest (33%) and urban land uses (14%). The Upper Opequon flows East and Northeast, discharging into the Lower Opequon. The Lower Opequon is a tributary of the Potomac River (USGS Hydrologic Unit Code 020700). The Potomac River discharges into the Chesapeake Bay.

2.1.3.c. Lower Opequon

A part of the Potomac River basin, the Lower Opequon Creek watershed (Segment ID VAV-B09R_OPE01A00) is located in Frederick and Clarke Counties, Virginia, surrounding the city of Winchester (Figure 2.2). The watershed is 52,873 acres in size. The Lower Opequon is mainly an agricultural watershed (about 50%) and is characterized by a rolling valley. The majority of the remainder of the watershed area is divided between forest (29%) and urban land uses (19%). The Lower Opequon discharges into the Potomac River (USGS Hydrologic Unit Code 020700). The Potomac River discharges into the Chesapeake Bay.

2.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with fecal coliform counts are potential sources of pathogenic organisms. For contact recreational activities such as boating and swimming, health risks increase with increasing fecal coliform counts. If the fecal coliform concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state fecal coliform standard for contact recreational uses. As discussed in Section 2.2.2, Virginia has adopted an *Escherichia coli* (*E. coli*) standard for water quality. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body.

Figure 2.1. Location of Abrams Creek watershed.

Figure 2.2. Location of Upper and Lower Opequon watersheds.

2.2. Designated Uses and Applicable Water Quality Standards

2.2.1. Designation of Uses (9 VAC 25-260-10)

> "A. All state waters are designated for the following uses: recreational uses (e.g. swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)".

Abrams Creek and Upper and Lower Opequon Creeks do not support the recreational (swimming) designated use due to violations of the bacteria criteria listed below.

2.2.2. Bacteria Standard (9 VAC 25-260-170)

EPA has recommended that all states adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than there is with fecal coliform. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. As of that date, the *E. coli* standard described below applies to all freshwater streams in Virginia. Additionally, prior to June 30, 2008, the interim fecal coliform standard must be applied at any sampling station that has fewer than 12 samples of *E. coli*.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards (as published in the Virginia Register Volume 18, Issue 20) the following criteria shall apply to protect primary contact recreational uses (VADEQ, 2000):

Interim Fecal Coliform Standard:

> Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water.

***Escherichia coli* Standard**:

> *E. coli* bacteria concentrations for freshwater shall not exceed a geometric mean of 126 counts per 100 mL for two or more samples taken during any

calendar month and shall not exceed an instantaneous single sample maximum of 235 cfu/100mL.

During any assessment period, if more than 10% of a station's samples exceed the applicable standard, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the segment into compliance with the water quality standard. The original impairment to Abrams Creek, Upper Opequon Creek, and Lower Opequon Creek was based on violations of an earlier fecal coliform standard that included a numeric single sample maximum limit of 1000 cfu/100 mL. The bacteria TMDL for these impaired segments will be developed to meet the *E. coli* standard. As recommended by VADEQ, the modeling will be conducted with fecal coliform inputs, and then a translator equation will be used to convert the output of the model to *E. coli*.

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

3.1.1. Abrams Creek

The Abrams Creek watershed was subdivided into 11 sub-watersheds for fecal coliform modeling purposes, as discussed in Section 5.2.1. The main branch of Abrams Creek runs for 10.8 miles from the headwaters to the confluence with Opequon Creek. Abrams Creek is perennial and has a trapezoidal channel cross-section. For the period of January 1980 through December 1988 (the hydrologic simulation calibration and validation period) at USGS gage 1616000 near the mouth of Abrams Creek, daily measured discharge ranged from 7.2 cubic feet per second (cfs) to 564 cfs, with a mean value of 26.6 cfs (USGS, 2003). Aquifers in this watershed are overlain by limestone (VWCB, 1985). Depth to the water table is generally in excess of 6 ft (SCS, 1982a). Several springs contribute flow to Abrams Creek, with the contributing area confined mainly to the topographic watershed boundaries.

3.1.2. Upper Opequon

The Upper Opequon watershed was subdivided into 16 sub-watersheds for fecal coliform modeling purposes, as discussed in Section 5.2.2. The main branch of Upper Opequon runs for 24.88 miles from the headwaters to the confluence with Abrams Creek. The Upper Opequon is perennial and has a trapezoidal channel cross-section. The Daily measured discharge for the period of October 1987 through September 1992 (the hydrologic simulation calibration and validation period) at USGS gage 1615000 on Opequon Creek near Berryville, VA, ranged from 2 cfs to 3,980 cfs with a mean value of 53 cfs (USGS, 2003). Aquifers in this watershed are overlain by limestone (VWCB, 1985). Depth to the water table is in excess of 6 ft (SCS, 1982).

3.1.3. Lower Opequon

The Lower Opequon watershed remnant was subdivided into 14 sub-watersheds for fecal coliform modeling purposes, as discussed in Section 5.2.3. The main branch of Lower

Opequon runs for 8.82 miles from the confluence of Upper Opequon Creek and Abrams Creek to the Virginia/West Virginia state line. The Lower Opequon is perennial and has a trapezoidal channel cross-section. The Lower Opequon is ungaged where it crosses the state line. Aquifers in this watershed are overlain by limestone (VWCB, 1985). Depth to the water table is in excess of 6 ft (SCS, 1982). The presence of numerous solution cavities and highly intense agricultural use result in a high potential for groundwater pollution from the surface (VWCB, 1985).

3.2. Ecoregion

Abrams Creek and the Opequon Creek watersheds are located in the Central Appalachian Ridge and Valley Level III Ecoregion. This ecoregion has numerous springs and caves. The ridges tend to be forested, while limestone valleys are composed of rich agricultural land (USEPA, 2002). Abrams Creek and the Upper and Lower Opequon Creeks also lie in the level IV ecoregions of the Northern Limestone/Dolomite Valleys and the Northern Shale Valleys. The Northern Limestone/Dolomite Valleys ecoregion has fertile land and is primarily agricultural. Steeper areas have scattered forests composed mainly of oak trees. Streams tend to flow year-round and have gentle slopes. The Northern Shale Valleys ecoregion has rolling valleys and low hills. The higher rate of soil erosion on this ecoregion causes increased turbidity in streams and a tendency toward stream impairment. This ecoregion is composed primarily of Appalachian Oak Forest or Oak-Hickory-Pine forest (Woods *et al.*, 1999).

3.3. Soils and Geology

The main soil map units found in the Abrams Creek watershed and in the portion of the Opequon Creek watersheds that lie in Frederick county are the Weikert-Berks-Blairton and Fredierick-Poplimnento-Oaklet soils, (SCS, 1982a). The Weikert-Berks-Blairton (stony silt loam) soils are gently sloping to moderately steep, shallow and moderately deep, well drained soils with a medium or fine textured subsoil, formed from weathered shale or sandstone. These soils are on broad, smooth or slightly convex uplands and in broad areas dissected by shallow drainageways (SCS, 1982a). The Fredierick-Poplimnento-Oaklet (loam) soils are gently sloping to very steep well-drained soils with fine textured subsoil. They are formed from weathered limestone. These soils are on gently sloping to moderately steep narrow to broad valley uplands dissected by some drainageways (SCS, 1982a).

The main soil map units found in the portion of the Opequon Creek watersheds that lie in Clarke County are the Berks-Endcav-Weikert, Carbo-Opequon-Oaklet, Rock outcrop-Opequon Swimley, and Rock outcrop-Hagertown-Swimley (SCS, 1982b). The Berks-Endcav-Weikert (silty clay loam) soils are shallow to deep, well-drained soils that have a loamy or clayey subsoil and formed in materials weathered from shale or calcareous shale on uplands (SCS, 1982b). The Carbo-Opequon-Oaklet (silty clay loam) soils are also shallow to deep, well-drained soils that have a clayey subsoil and formed in materials weathered from limestone on uplands (SCS, 1982b). The Rock outcrop-Opequon-Swimley and Rock outcrop-Hagertown-Swimley (silt loam) soils are shallow and deep, well-drained soils with clayey subsoil and are formed in materials weathered from limestone on uplands. Areas of rock outcrop are comprised mainly of limestone and some dolomite (SCS, 1982b).

3.4. Climate

The climate of the Abrams Creek and Opequon Creek watersheds is characterized based on the meteorological observations made by the National Weather Service's cooperative observer in Winchester. The weather station is located within the Abrams Creek watershed. Average annual precipitation is 38.29 in. with 56% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2002). Average annual snowfall is 22.5 in. with the highest snowfall occurring during January (SERCC, 2002). Average annual daily temperature is 53.7°F. The highest average daily temperature of 74.9°F occurs in July while the lowest average daily temperature of 31.9°F occurs in January (SERCC, 2002).

3.5. Existing Land-use

3.5.1. Abrams Creek

Residential developments comprise the main land use category in the Abrams Creek watershed, covering 33% of the total watershed area. Other urban developments (commercial, industrial, and transportation, for example) cover another 17% of the watershed. These urban land uses are concentrated in the City of Winchester. Forest, pasture, and cropland account for 22%, 21%, and 6% of the watershed area, respectively. The non-urban land uses are located primarily in the western and eastern portions of the watershed, outside the Winchester city limits. The remaining area is covered by water or barren land.

3.5.2. Upper Opequon

Agriculture comprises the main land use category in the Upper Opequon watershed, at 53% of the total watershed area. Of this, pasture covers 48% and cropland accounts for about 5% of the total watershed area. Other urban developments (commercial, industrial, and transportation, for example) cover another 14% of the watershed. The urban landuses are concentrated in and around the City of Winchester. Forest acreage accounts for about 33% of the total watershed area.

3.5.3. Lower Opequon

Agriculture comprises the main land use category in the Lower Opequon watershed, covering 52% of the total watershed area. Pasture covers 47% and cropland accounts for about 5% of the watershed area. Forest acreage accounts for about 29% of the total area. Urban land uses cover about 19% of the Lower Opequon. The Lower Opequon includes the Abrams Creek watershed, which includes the City of Winchester. The urban land uses in the Lower Opequon are concentrated in and to the north of the City of Winchester. The remaining area is covered by water or barren land.

3.6. Future Land Use

The Opequon Creek watershed is experiencing urban development and growth, which must be accounted for in the TMDL development process. Future land use scenarios were created based on the following assumptions:

- Future urban development would occur within Frederick County's "Urban Development Areas" (UDAs) and "Commercial Centers" (ComCntrs)
- Agricultural and forestry land uses within these areas would decrease to 0% under full build-out
- Water, transitional, and urban greenspace areas would remain the same
- Commercial and residential land uses within these areas would increase in proportion to their existing ratios for UDAs; land use in ComCntrs would increase only in the commercial land use category.

The Opequon Creek watershed was sub-divided into three areas for this analysis, as shown in Figure 3.1 – Abrams Creek, Upper Opequon Creek, and the Lower Opequon Remnant. The name - Lower Opequon Remnant – was given to this area because, although the whole watershed drains to the Lower Opequon, this portion is a downstream portion that remains once the other two headwater sub-watersheds (Upper Opequon Creek and Abrams Creek) are separated out. The area summaries and redistribution for future scenarios was performed independently within each of these watershed areas. Three future scenarios were then created based on 25%, 50%, and 100% build-out within the UDAs and ComCntrs shown in Figure 3.1, and were named Future25, Future50, and Future100.

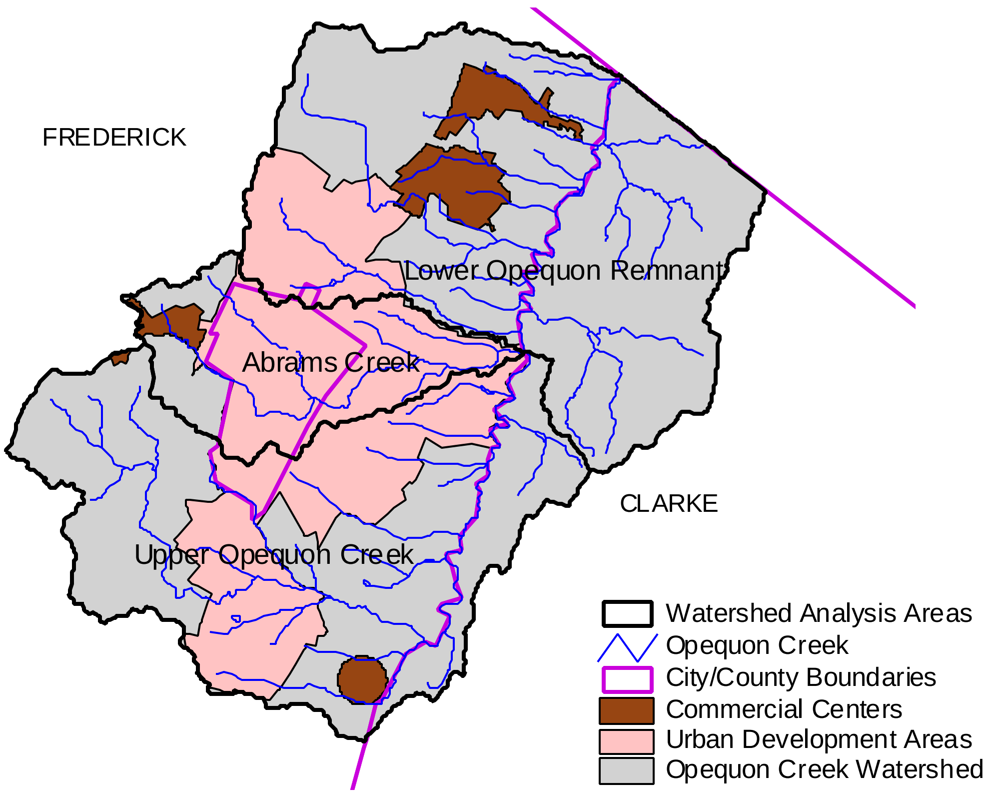

Figure 3.1. Areas Subject to Future Development in the Opequon Creek Watershed.

The area encompassed by the UDAs and ComCntrs is approximately 5,051 ac, or 34% of the entire watershed. Of that area, 2,004 ac is already in commercial or residential use, or is not subject to change, leaving a maximum area of 3,047 ac (21%) subject to change during the 100% build-out scenario. A summary of the broad land use distributions for the entire Opequon Creek watershed for existing and the three future build-out scenarios is given in Table 3.1. Spreadsheets showing the detailed creation of the alternative future scenarios are included in Appendix B.

Table 3.1. Land use Distribution for Existing and Future Scenarios.

Landuse Category	Existing	Future25	Future50	Future100
Agriculture	56.5%	53.3%	50.0%	43.6%
Urban	16.9%	22.1%	27.3%	37.7%
Forest	26.6%	24.6%	22.6%	18.6%

3.7. Water Quality Data

Virginia DEQ monitored chemical and bacterial water quality in Abrams Creek on a monthly basis from August 1976 through March 2003, in the Upper Opequon from August 1991 through March 2003, and in the Lower Opequon from April 1979 through June 2001.

3.7.1. Historic Data – Fecal Coliform

3.7.1.a. Abrams Creek Data

The Virginia Department of Conservation and Recreation (VADCR) has assessed the Abrams Creek watershed as having a high potential for nonpoint source pollution from urban sources. Of the 58 water quality samples collected from July 1992 through June 1997 (the 1998 303d 5–yr listing period) at the outlet of the watershed, 17% of the samples exceeded the instantaneous standard of 1,000 cfu/100 mL. Consequently, this segment of Abrams Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a,b).

Virginia DEQ personnel monitored pollutant concentrations at the Abrams Creek watershed outlet (Station ID No. 1AABR000.78) on a monthly basis over 27 years (1976-2003). Time series data of fecal coliform concentration from July 1992 (the beginning of the 1998 303d 5-yr listing period) through the most recent data collected at the time this report was written are shown in Figure 3.2. The Most Probable Number (MPN) method was used for analyzing water samples for fecal coliform concentration. The MPN method had a maximum detection limit or "cap" of 8,000 cfu/100 mL.

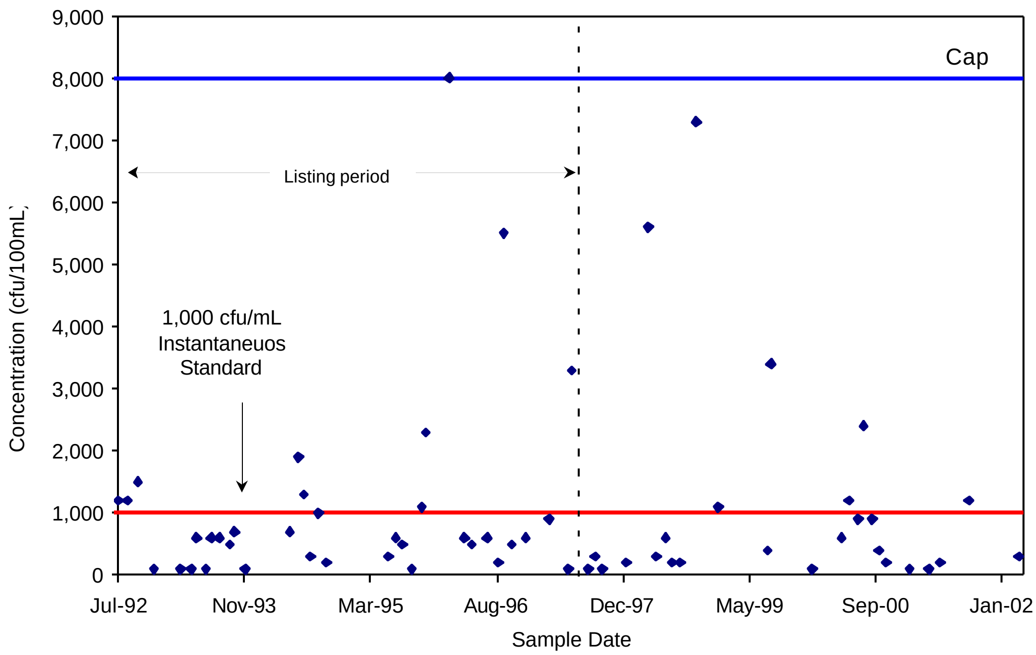

Figure 3.2. Fecal coliform concentration in Abrams Creek.

Seasonality of fecal coliform concentration in the streams was evaluated by plotting the mean monthly fecal coliform concentration values (Figure 3.3). Mean monthly fecal coliform concentration was determined as the average of six to twenty-one values for each month; the number of values varied according to the available number of samples for each month in the 1976 to 2003 period of record. The data indicate that higher in-stream fecal coliform concentrations occur during the late winter/early spring and early fall months, with lower concentrations in the remaining months, except for July. It should be noted that due to the cap imposed on the fecal coliform count (8,000 cfu/100 mL), the actual counts could be much higher in cases where fecal coliform levels are equal to these maximum levels, therefore increasing the averages shown in Figure 3.3.

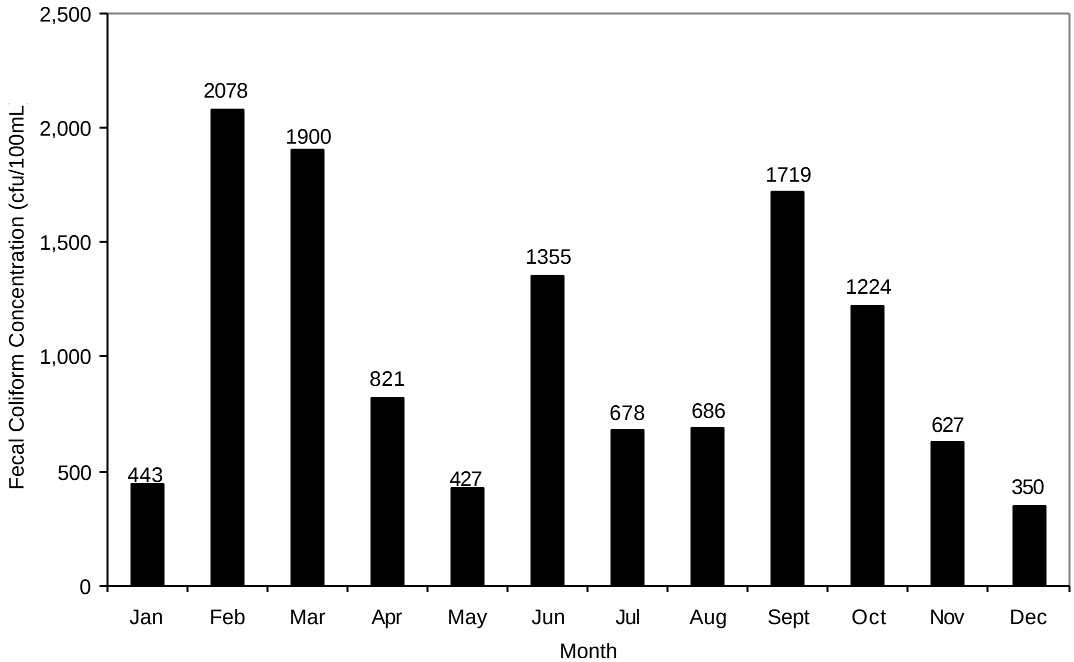

Figure 3.3. Impact of seasonality on fecal coliform concentrations. Average monthly fecal coliform concentration is the mean of six to twenty-one values for each month, collected over a twenty-seven-year period (1976-2003).

The relationship between stream flow rates and fecal coliform concentrations is shown in Figure 3.4. The stream flow rate and fecal coliform concentration data in Figure 3.4 are for the period from July 1992 through October 1994, when both data sets were available.

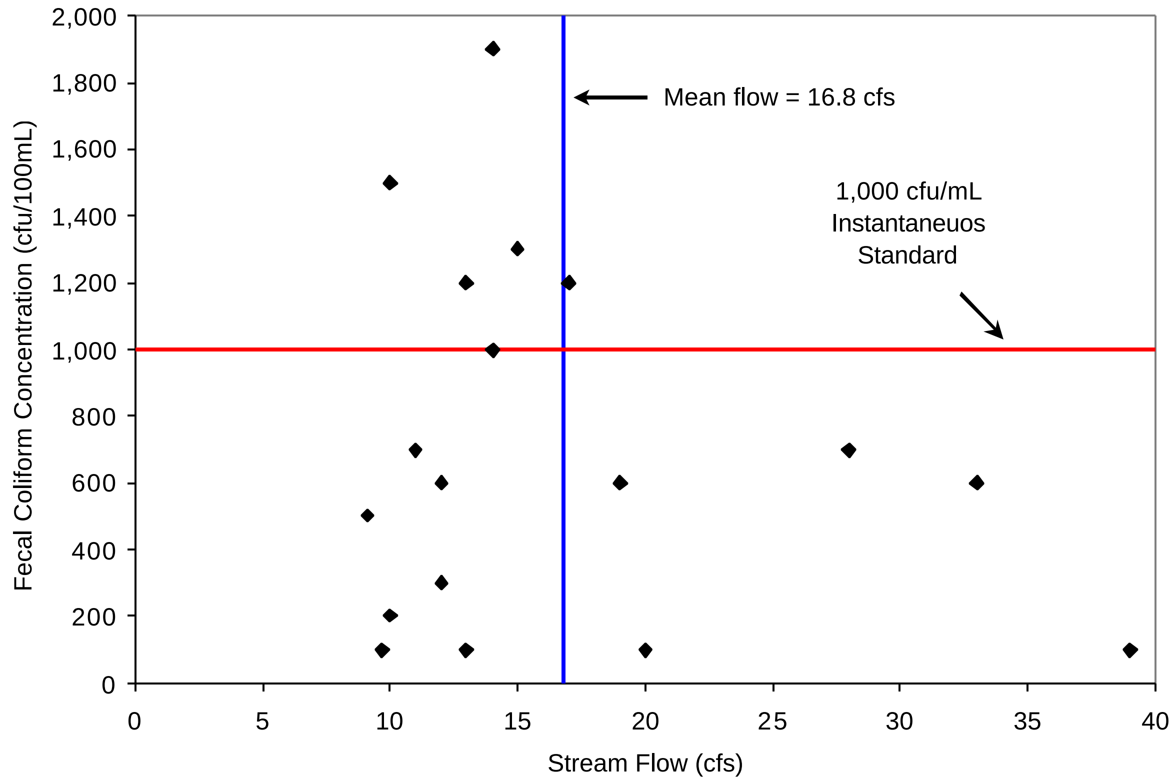

Figure 3.4. Relationship between stream flow and fecal coliform concentration from July 1992 through October 1994.

Based on daily flow measurements, the mean stream flow in Abrams Creek was 16.8 cfs. Thirty-three percent of fecal coliform samples exceeded the instantaneous criterion of 1,000 cfu/100 mL (Figure 3.4) when flows were lower than the mean value of 16.8 cfs. When flows exceeded the mean flow (16.8 cfs), 14% of the samples exceeded the instantaneous standard. Most (63%) of the measurements were made when flow values were lower than the mean value. Higher fecal coliform concentrations under flow conditions less than mean flow rates suggest that fecal coliform directly deposited/discharged into the stream may be a dominant source of fecal coliform in the watershed.

3.7.1.b. Upper Opequon Data

The VADCR has assessed the Upper Opequon watershed as having a high potential for nonpoint source pollution from agricultural sources. Of the 58 water quality samples collected from July 1992 through June 1997 at the outlet of the watershed, 19% of the samples exceeded the instantaneous standard of 1,000 cfu/100 mL. Consequently, this segment of Upper Opequon Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b). Given that water samples were collected on a monthly basis, the geometric mean criterion could not be calculated.

Virginia DEQ personnel monitored pollutant concentrations at the Upper Opequon watershed outlet (Station ID No. 1AOPE036.13) on a monthly basis over 12 years (1991-2003). Time series data of fecal coliform concentration from July 1992 (the beginning of the 1998 303d 5-yr listing period) through the most recent data collected at the time of this report are shown in Figure 3.5. The Most Probable Number (MPN) method was used for analyzing water samples for fecal coliform concentration. The MPN method had a maximum detection limit or "cap" of 8,000 cfu/100 mL.

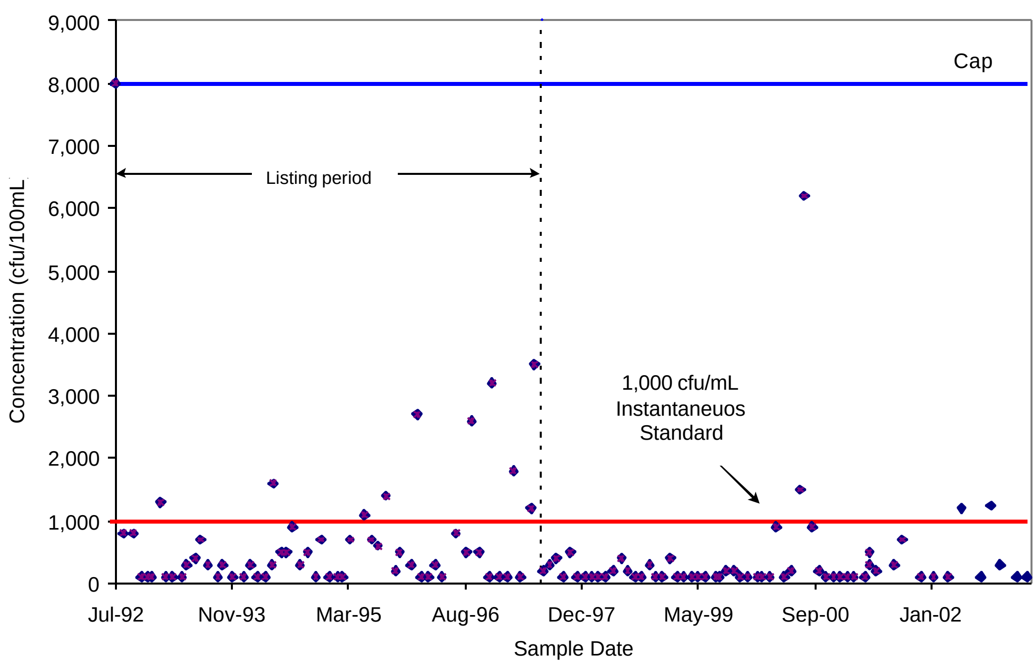

Figure 3.5. Fecal coliform concentration in Upper Opequon.

Seasonality of fecal coliform concentration in the streams was evaluated by plotting the mean monthly fecal coliform concentration values (Figure 3.6). Mean monthly fecal coliform concentration was determined as the average of eight to nine values for each month; the number of values varied according to the available number of samples for each month in the 1992 to 2003 period of record.

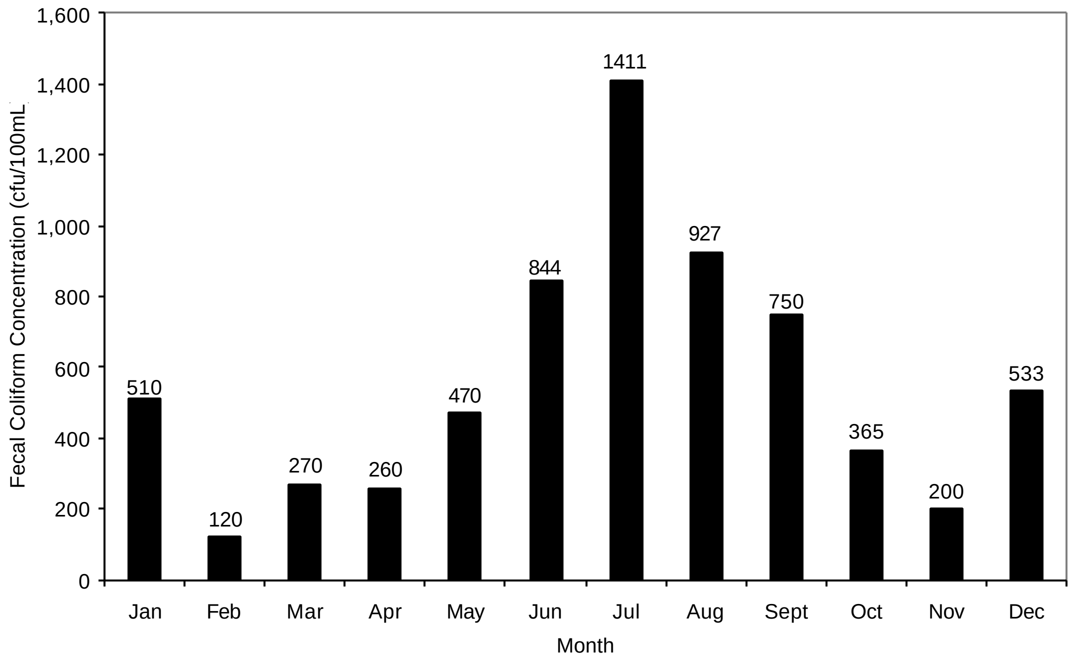

Figure 3.6. Impact of seasonality on fecal coliform concentrations. Average monthly fecal coliform concentration is the mean of eight to nine values for each month, collected over an eleven-year period (1992-2003).

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the summer months and lower concentrations typically occurring during the winter months. During the summer (June – August), the average fecal coliform concentration was 1,061 cfu/100mL compared with 388 cfu/100mL during the winter (December – February). Lower fecal coliform concentrations measured during the winter and spring months (Figure 3.6) could be due to larger number of animals being in confinement during these periods, resulting in smaller fecal coliform loading to the pasture, and particularly to streams. Furthermore, land application of animal waste is limited during the winter months. Higher fecal concentrations during the summer and fall months (Figure 3.6) could be due to more cattle in streams and more animal waste land-applied during the fall. The highest fecal coliform concentration observed during July (Figure 3.6) could also be due to a large proportion of animal waste being applied to crops during or prior to this month. Similarly, high fecal coliform concentrations observed in December (Figure 3.6) could be due to land-application of animal waste to the winter cover crop during the fall and/or to land-application of animal waste in order to create storage space for animal waste generated during winter. It should be noted that due to the cap imposed on the fecal coliform count (8,000 cfu/100 mL), the actual counts could be much higher in cases where fecal coliform levels are equal to these maximum levels, therefore increasing the averages shown in Figure 3.6.

The relationship between stream flow rates and fecal coliform concentrations is shown in Figure 3.7. The stream flow rate and fecal coliform concentration data in Figure 3.7 are for the period from July 1992 through October 1997, when both data sets were available.

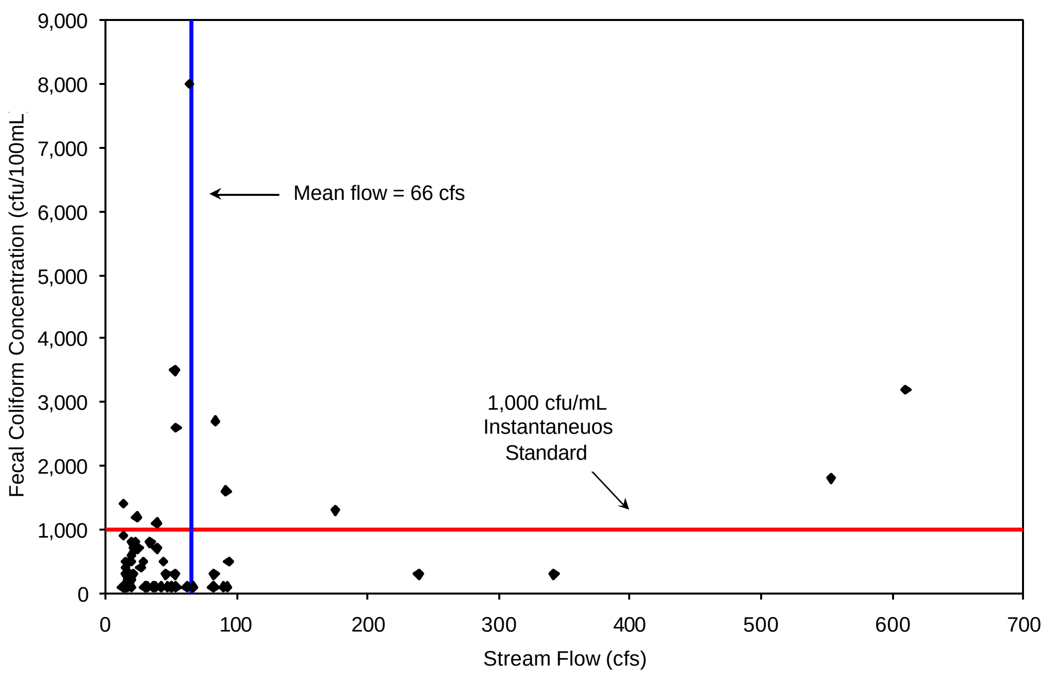

Figure 3.7. Relationship between stream flow and fecal coliform concentration from July 1992 through October 1997.

Based on daily flow measurements made from July 1992 through October 1997, mean stream flow in Upper Opequon was 66 cfs. Thirteen percent of fecal coliform samples exceeded the instantaneous criterion of 1,000 cfu/100 mL (Figure 3.7) when flows were lower than the mean value of 66 cfs. When flows exceeded the mean flow (66 cfs), 36% of the samples exceeded the instantaneous standard. However, most (77%) of the measurements were made when flow values were lower than the mean value. Higher fecal coliform concentrations under flow conditions greater than mean flow rates suggest that fecal coliform coming in runoff from upland areas may be a dominant source of bacteria in the watershed.

3.7.1.c. Lower Opequon Data

The VADCR has assessed the Lower Opequon watershed as having a high potential for nonpoint source pollution from agricultural sources. Of the 59 water quality samples collected during July 1992 through June 1997 near the outlet of the watershed, 12% of the samples exceeded the instantaneous standard of 1,000 cfu/100 mL. Consequently, this segment of Lower Opequon Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b). Given that water samples were collected on a monthly basis, the geometric mean criterion could not be calculated.

Virginia DEQ personnel monitored pollutant concentrations near the Lower Opequon Creek watershed outlet (Station ID No. 1AOPE025.10) on a monthly basis over 22 years (1979-2001). Time series data of fecal coliform concentration from July 1992 (the beginning of the 1998 303d 5-yr listing period) through the most recent data collected at the time of this report are shown in Figure 3.8. The Most Probable Number (MPN) method was used for analyzing water samples for fecal coliform concentration. The MPN method had a maximum detection limit or "cap" of 8,000 cfu/100 mL.

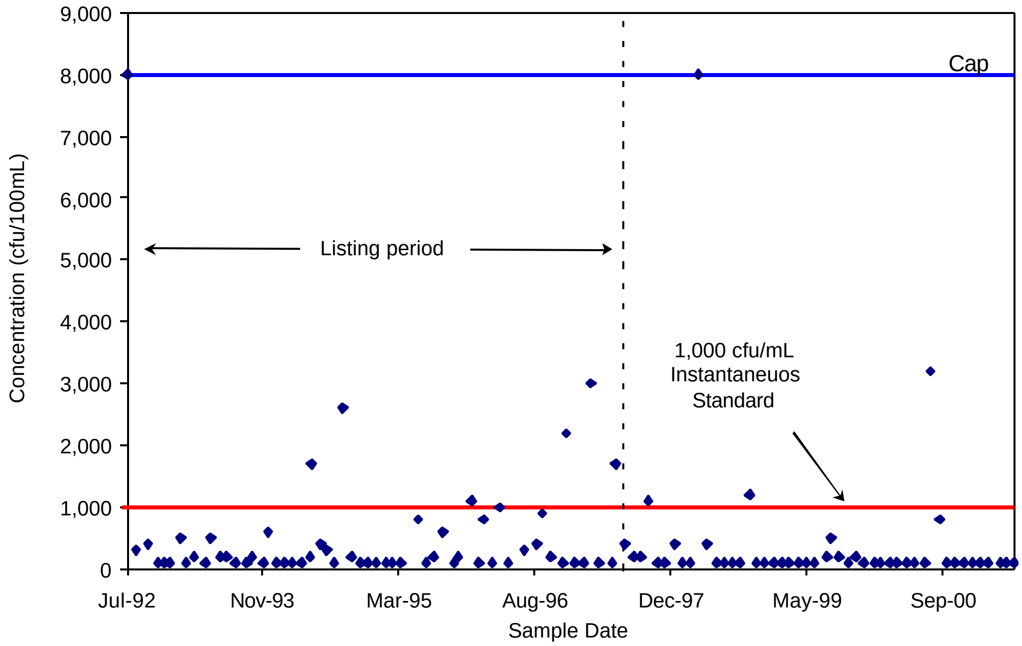

Figure 3.8. Fecal coliform concentration in Lower Opequon.

Seasonality of fecal coliform concentration in the streams was evaluated by plotting the mean monthly fecal coliform concentration values (Figure 3.9). Mean monthly fecal coliform concentration was determined as the average of eight to nine values for each month; the number of values varied according to the available number of samples for each month in the 1992 to 2001 period of record.

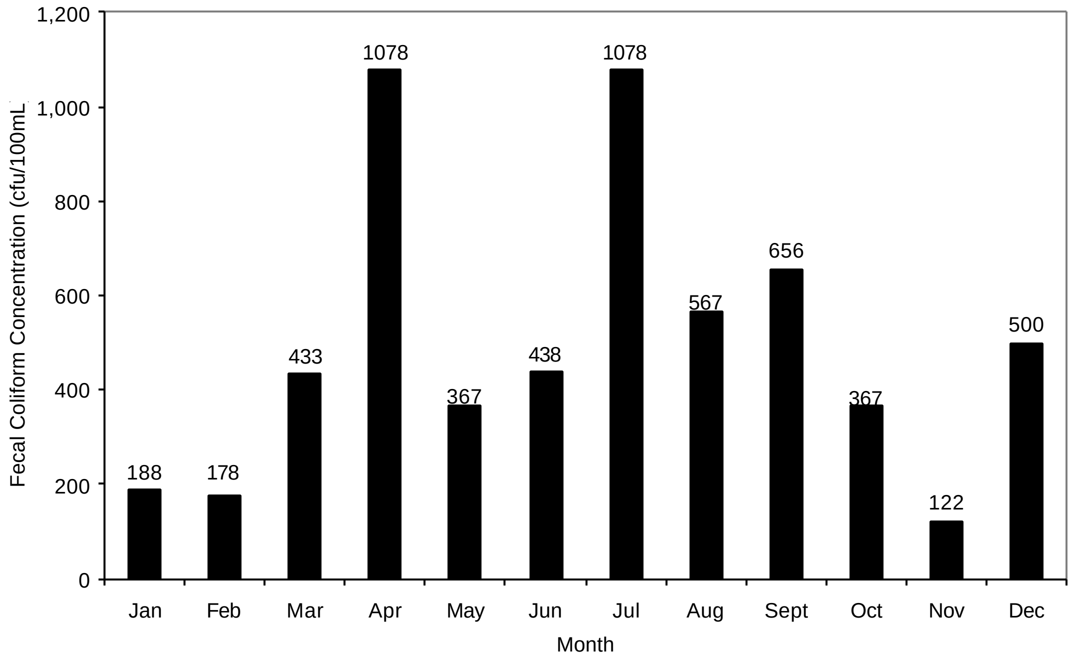

Figure 3.9. Impact of seasonality on fecal coliform concentrations. Average monthly fecal coliform concentration is the mean of eight to nine values for each month, collected over an nine-year period (1992-2001).

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the late summer and early fall months and lower concentrations typically occurring during the winter months. During summer and early fall (June – September), the average fecal coliform concentration was 685 cfu/100mL compared with 289 cfu/100mL during winter (December – February). Land application of animal waste is limited during the winter months. Higher fecal concentrations during the summer and fall months (Figure 3.9) could be due to more cattle in streams and more animal waste land-applied during the fall. The high fecal coliform concentration observed during April (Figure Figure 3.9) could also be due to a large proportion of animal waste being applied to cropland during or prior to this month. It should be noted that due to the cap imposed on the fecal coliform count (8,000 cfu/100 mL), the actual counts could be much higher in cases where fecal coliform levels are equal to these maximum levels, therefore increasing the averages shown in Figure 3.9.

There is no gaging station on the Lower Opequon before it crosses into West Virginia. Therefore, no examination of the relationship between stream flow rates and fecal coliform concentrations is possible.

CHAPTER 4: SOURCE ASSESSMENT OF FECAL COLIFORM

Potential fecal coliform sources in the Abrams Creek and the Opequon Creek watersheds were assessed using multiple approaches, including information from VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), NRCS, public participation, watershed reconnaissance and monitoring, published information, and professional judgment.

Point sources of fecal coliform bacteria in the Abrams Creek and Opequon Creek watersheds include all municipal and industrial plants that treat human waste, as well as private residences that fall under general permits. Virginia issues Virginia Pollutant Discharge Elimination System (VPDES) permits for point sources of pollution. In Virginia, point sources that treat human waste are required to maintain a fecal coliform concentration of 200 cfu/100 mL or less in their effluent. Tables 4.1 (VPDES permits) and 4.2 (general permits, less than or equal to 1000 gallons per day) show the point sources of pollution in the Abrams Creek and Opequon Creek watersheds. Only two of the VPDES permitted dischargers listed are permitted to discharge fecal coliform. There were no general permits or VPDES permits in the Abrams Creek watershed. In allocation scenarios, the entire allowable point source discharge concentration of 200 cfu/100 mL was used.

Additionally, two Phase II municipal separate storm sewer system (MS4) permits have been issued in the Abrams Creek watershed for the City of Winchester (VAR040053) and VDOT-Winchester Urban Area (VAR040032). These permits are designed to compel awareness of the quality of water discharging from publicly owned storm sewer outfalls, and to reduce pollution from the MS4, although no numerical limits for any specific water quality parameter are stipulated in these permits. The permits blur the lines that have traditionally distinguished point and nonpoint sources of pollution. While the MS4 permits are regulated similarly to point source discharges, water quality discharging from the MS4s is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). Fecal coliform loads modeled from impervious areas within the MS4 areas are included in the wasteload allocation (WLA) component of the TMDL, in compliance with 40 CFR §130.2(h). Fecal coliform loads related to stormwater runoff from areas covered by MS4 permits were modeled with HSPF as contributions from impervious land use categories.

Table 4.1. VPDES Permitted Point Sources in the Abrams Creek, Upper and Lower Opequon Creek Watersheds.

Permit Number	Owner	Facility	Receiving Stream	Sub-Watershed Location	Flow (MGD)	Permitted FC Conc.	FC Load (cfu/year)
VA0002739	S.M. Perry, Inc.	S.M. Perry - Winchester	Abrams Creek	ABR-10	0.099	NA	NA
VA0051373	National Fruit Product Company, Inc.	National Fruit - Winchester	Abrams Creek	ABR-08	0.032	NA	NA
VA0076384	Abex Corporation	Abex	Abrams Creek	ABR-09	0.215	NA	NA
VA0089150[a]	Winchester Medical Center STP	Winchester Medical Center	Abrams Creek	ABR-10	--	NA	NA
VA0075191	Frederick-Winchester Service Authority	Parkins Mills STP	Upper Opequon	B08-11	2.0	200 cfu/ 100 mL	$5.52*10^{12}$
VA0088471	Fredrick County	Fredrick County Landfill	Upper Opequon	B08-08	0.08	NA	NA
VA0088722	Stonebrook Swim and Raquet Club	Stonebrook Swim and Raquet Club	Upper Opequon	B08-15	0.004	NA	NA
VA0089010	Franciscan Center	Franciscan Center	Upper Opequon	B08-11	0.0016	NA	NA
VA0065552[b]	Frederick-Winchester Service Authority	Opequon Region AWT	Lower Opequon	B08-02	12.2[b]	200 cfu/ 100 mL	$3.37*10^{13}$
VA0023116	Virginia Department of Highways	I-81 Rest Area STP	Lower Opequon	B09-06	0.015	NA	NA
VA0002020[a]	W.S. Frey Company, Inc.	W.S. Frey	Lower Opequon	B09-06	--	NA	NA
VA0029653	Shalom et Benedictus	Shalom et Benedictus Lagoon	Lower Opequon	B09-08	0.007	NA	NA
VA0090808	APAC- Virginia, Inc.	APAC Virginia WWTP	Lower Opequon	B09-06	0.005	NA	NA

[a]No Flow Data Available
[b]Located above the Abrams and Opequon confluence, but discharges into the Lower Opequon. Design flow is 8.4 MGD for June-November and 16 MGD for December – May, the average is 12.2 MGD

Table 4.2. General Permits discharging into Upper and Lower Opequon Creeks.

Permit Number	Facility Name	City	Discharge Type	Sub-Watershed	Design Flow (gpd)	Permitted FC Conc. (cfu/100mL)	FC Load (cfu/year)
VAG401136	Homeowner	Winchester	Single Family House (SFH)	B08-13	1000	200	2.76×10^9
VAG401243	Homeowner	White Post	SFH	B08-11	1000	200	2.76×10^9
VAG401171	Homeowner, Woods Mill Subdivision, Lot 4	Stephenson	SFH	B09-13	1000	200	2.76×10^9
VAG401928	Homeowner, Opequon Estates, Lot 8	Stephenson	Retired (RET)	B09-10	1000	200	2.76×10^9
VAG401546	Homeowner, 699 Carpers Valley Road	Winchester	SFH	B08-8	1000	200	2.76×10^9
VAG401815	Homeowner, Route 522 x SR 644, Parkins Mill	Winchester	Private (PRVT)	B08-13	1000	200	2.76×10^9
VAG401042	Homeowner, 120 Jackson Drive	Winchester	SFH	B08-10	1000	200	2.76×10^9
VAG401074	Homeowner	Winchester	RET	B08-10	1000	200	2.76×10^9
VAG401102	Homeowner	Winchester	RET	B08-10	1000	200	2.76×10^9
VAG401135	Homeowner, Parkins Mill Road	Winchester	SFH	B08-11	1000	200	2.76×10^9
VAG401304	Homeowner, 986 Singhass Road	Winchester	SFH	B08-16	1000	200	2.76×10^9
VAG401326	Homeowner, 192 Dundridge Drive, White Post	Winchester	SFH	B08-11	1000	200	2.76×10^9
VAG401357	Homeowner, N side of SR 642, just E of Route 522	White Post	SFH	B08-11	1000	200	2.76×10^9
VAG401446	Homeowner, 1681 Airport Road	Winchester	SFH	B08-10	1000	200	2.76×10^9
VAG401558	Homeowner, 190 E Parkins Mill Road	Winchester	SFH	B08-10	1000	200	2.76×10^9
VAG401812	Homeowner, 206 Knight Drive	White Post	SFH	B08-11	1000	200	2.76×10^9
VAG401827	Homeowner, 340 W Parkins Mill Road	Winchester	SFH	B08-10	1000	200	2.76×10^9
VAG401821	Homeowner, E side SR 662, just N of SR 661	Winchester	SFH	B09-8	1000	200	2.76×10^9
VAG401106	Homeowner, 261 Lick Run Crossing	Stephenson	SFH	B09-8	1000	200	2.76×10^9
VAG401828	Homeowner, Woods Mill, Lot 12	Stephenson	SFH	B09-8	1000	200	2.76×10^9

Table 4.2. General Permits discharging into Upper and Lower Opequon Creeks. (continued)

VAG401892	Homeowner, NE of SR 661/662, NE of Winchester	Stephenson	SFH	B09-8	1000	200	$2.76x10^9$
VAG401485	Homeowner, 957 Moose Road	Berryville	SFH	B09-11	1000	200	$2.76x10^9$
VAG401264	Homeowner, 2431 Cedar Creek Grade	Silver Spring	RET	B08-16	1000	200	$2.76x10^9$
VAG401022	Homeowner, 418 Rocky Ford Road	Clearbrook	SFH	B09-5	1000	200	$2.76x10^9$
VAG401126	Homeowner, 121 Forgotten Lane, Clearbrook	Brucetown	SFH	B09-1	1000	200	$2.76x10^9$
VAG401209	Homeowner, Burnt Factory Road	Stephenson	SFH	B09-10	1000	200	$2.76x10^9$
VAG401240	Homeowner, 116 Frasher Drive, Clear Brook	Springfield	SFH	B09-5	1000	200	$2.76x10^9$
VAG401255	Homeowner, 100 Dogwood Lane	Stephenson	SFH	B09-6 & B09-7	1000	200	$2.76x10^9$
VAG401279	Homeowner, N side of Old Braddock Road (SR 667), NE of Brucetown	Stephenson	SFH	B09-6	1000	200	$2.76x10^9$
VAG401280	Homeowner, E side of SR 664, N of Burnt Factory	Stephens City	SFH	B09-10	1000	200	$2.76x10^9$
VAG401335	Homeowner, 1020 Old Charlestown Road	Stephenson	SFH	B09-7	1000	200	$2.76x10^9$
VAG401695	Homeowner, 116 Oak Hill Lane	Stephenson	SFH	B09-7	1000	200	$2.76x10^9$
VAG401788	Homeowner, SR 660 - High Banks Road	Stephenson	SFH	B09-10	1000	200	$2.76x10^9$
VAG401903	Homeowner, Stephenson Heights Subdivision, Lot 8	Stephenson	SFH	B09-7	1000	200	$2.76x10^9$
VAG401975	Homeowner, S side SR644, 0.3 mi W of Rt 17/50	Winchester	PRVT	B08-10 & B08-11	1000	200	$2.76x10^9$
VAG401586	Homeowner, SR 661 (Redbud Road), across from Redbud Church	Winchester	SFH	B09-13	1000	200	$2.76x10^9$
VAG401163	Homeowner, N side of SR 661(Redbud Road), approx. 0.2 mi W of SR 660	Winchester	SFH	B09-13	1000	200	$2.76x10^9$
VAG401137	Homeowner, 2088 Brucetown Road	Brucetown	SFH	B09-5	1000	200	$2.76x10^9$
VAG401511	Homeowner	Clearbrook	SFH	B09-5	1000	200	$2.76x10^9$
VAG401946	Homeowner, N side of SR 672 (Brucetown Road), E of Brucetown	Clearbrook	SFH	B09-1 & B09-5	1000	200	$2.76x10^9$
VAG401593	Homeowner, 1673 Brucetown Road	Clearbrook	SFH	B09-1	1000	200	$2.76x10^9$
VAG401117	Homeowner, 180 Backwoods Lane, Clearbrook	Clearbrook	SFH	B09-1	1000	200	$2.76x10^9$
VAG401594	Homeowner, 1677 Brucetown Road	Clearbrook	SFH	B09-1	1000	200	$2.76x10^9$

4.1. Abrams Creek Sources

A synopsis of the fecal coliform sources characterized and accounted for in the Abrams Creek watershed, along with average fecal coliform production rates are shown in Table 4.3.

Table 4.3. Potential fecal coliform sources and daily fecal coliform production by source in Abrams Creek watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	29,733	1,950[a]
Beef cattle	391	33,000[b]
Pets	14,642	450[c]
Deer	574	347[d]
Raccoon	265	113[d]
Muskrat	376	25[d]
Beaver	14	0.3[e]
Wild Turkey	60	93[f]
Duck	134	2,430[f]
Goose	4,961	799[d]

[a]Source: Geldreich *et al.* (1978)
[b]Based on ASAE (1998) fecal coliform production ratio of beef cattle to milk cow and fecal coliform produced by a milk cow
[c]Source: Weiskel *et al.* (1996)
[d]Source: Yagow (2001)
[e]Source: MapTech, Inc. (2000)
[f]Source: ASAE (1998)

4.1.1. Humans and Pets

The Abrams Creek watershed has an estimated population of 29,762 people (14,642 households at an average of 2.033 people per household; actual people per household varies among sub-watersheds). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

4.1.1.a. Failing Septic Systems

Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed that no die-off occurred once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters. Households were located using data obtained from the Frederick and Clarke County Planning Departments. Each unsewered household was classified into one of three age categories (pre-1967, 1967-1987, and post-1987) based on USGS 7.5-min. topographic maps which were initially created using 1967 photographs and were photo-revised in 1987. Professional judgment was applied in assuming that septic system failure rates for houses in the pre-1967, 1967-1987, and post-1987 age categories were 40, 20, and 3%, respectively (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, VA.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate ranged from 1.9 to 2.7 persons per household based on the 2000 Census) by the per capita fecal coliform production rate of 1.95×10^{9} cfu/day (Geldreich *et al.*, 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 1.9 persons/household was 3.71×10^{9} cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.4.

4.1.1.b. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1967 and 1967-1987 age categories, 10%, and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, VA.). Based on these criteria, it was estimated that there were no straight pipes in the watershed.

4.1.1.c. Pets

Assuming one pet per household, there are an estimated 14,642 pets in the Abrams Creek watershed. A dog produces fecal coliform at a rate of 0.45×10^{9} cfu/day (Weiskel *et al.*, 1996); this was assumed to be representative of a ‘unit pet’ – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table 4.4. Pet waste is generated in the Urban and High and Low Density Residential land use types. Surface runoff can transport bacteria in pet waste from residential areas to the stream.

Table 4.4. Estimated number of unsewered houses by age category, number of failing septic systems, and pet population in Abrams Creek watershed.

Subwatershed	Unsewered houses in each age category (no.)[a]			Failing septic systems (no.)	Pet population[b]
	Pre-1967	1967-1987	Post-1987		
ABR-01	0	1	0	0	3
ABR-02	0	2	0	0	591
ABR-03	0	0	0	0	184
ABR-04	0	0	0	0	418
ABR-05	0	0	0	0	322
ABR-06	0	0	0	0	2,158
ABR-07	0	0	0	0	2,790
ABR-08	0	0	0	0	3,637
ABR-09	1	2	10	1	3,248
ABR-10	92	21	30	42	436
ABR-11	3	0	6	1	855
Total	*96*	*26*	*46*	*44*	*14,642*

[a]No households were estimated to have straight pipes, and 14,474 households were sewered. Adding these numbers to the numbers above yields the total number of households, 14,642.
[b]Assumed an average of one unit pet per household. Includes pets from sewered households.

4.1.2. Cattle

In the Abrams Creek watershed, fecal coliform from beef cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from collected waste that is applied to crop and hay land. Beef cattle numbers in the Abrams Creek watershed were estimated by communicating with NRCS, VADCR, VCE, local producers, the staff at the Farmer's Livestock Exchange Auction, and visits to the watershed. There are no dairies in the watershed.

4.1.2.a. Distribution of Beef Cattle in the Abrams Creek Watershed

The beef population was distributed among the sub-watersheds based on the location of the operations (Table 4.5). On average there are approximately 391 head in the Abrams Creek watershed on a daily basis. Two-hundred and twenty-five head are maintained in cow/calf operations. The remainder is due to the Farmer's Livestock

Exchange located on Hwy. 50 (sub-watershed ABR-10). The auction holds a sale every Monday throughout the year. In April, September, and October, the auction holds a second sale each week. Based upon input from Exchange staff, an average of 1,250 heads pass through the auction each week. Because some cattle arrive at the auction before the sale day and some cattle remain after sale day, the assumption was made that 166 cattle were present in the watershed on a daily basis in the months with one sale per week, this number doubles in the months with two sales per week.

Table 4.5. Distribution of beef cattle among Abrams Creek sub-watersheds.

Sub-watershed	Beef cattle (head)
ABR-01	50
ABR-02	0
ABR-03	0
ABR-04	0
ABR-05	0
ABR-06	0
ABR-07	0
ABR-08	0
ABR-09	0
ABR-10	291[a]
ABR-11	50
Total	391

[a]An additional 166 head per day are present in sub-watershed ABR-10 in the months of April, October, and November.

Cattle spend varying amounts of time in streams and pasture depending on the time of year. Accordingly, the proportion of fecal coliform deposited on any given land area varies throughout the year. The following assumptions were used to estimate the distribution of cattle and their manure:

a) Cows that are not in loafing lots will be on pasture and in the streams;

b) Pasture 1 (improved pasture/hayland) will support twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which supports twice as many cows per unit area as pasture 3 (overgrazed pasture);

c) Cows on pastures that are contiguous to streams have stream access (Table 4.6);

d) Cows with stream access spend varying amounts of time in and around the streams during different seasons (Table 4.7). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons; and

e) Ten percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 90% of the manure is deposited on pastures near the stream.

Table 4.6. Percent of cows having stream access in Abrams Creek.

Sub-watershed	Pasture 1
	%[a]
ABR-01	10
ABR-02	--
ABR-03	--
ABR-04	--
ABR-05	--
ABR-06	--
ABR-07	--
ABR-08	--
ABR-09	--
ABR-10	25
ABR-11	25

[a]Percent of cows in this pasture category in each sub-watershed that have access to streams that sub-watershed. No Pasture 2 or Pasture 3 areas in Abrams Creek were contiguous to stream.

Table 4.7. Time spent by beef cattle in confinement and in the stream.

Month	Time spent in confinement (%)	Time spent in the stream (hours/day)[a]
January	0	0.50
February	0	0.50
March	0	0.75
April	0	1.00
May	0	1.50
June	0	3.50
July	0	3.50
August	0	3.50
September	0	1.50

October	0	1.00
November	0	0.75
December	0	0.50

[a]Time spent in and around the stream by cows that have stream access.

The numbers of cattle in each land use type as well as in the stream for all sub-watersheds are given in Table 4.8 for beef cattle. An example calculation for this breakdown is given for a Lower Opequon subwatershed in Appendix C.

Table 4.8. Distribution of the beef cattle population in Abrams Creek Watershed.

Months	Pasture 1	Pasture 2	Stream[a]	Loafing
January	216.5	8.5	0.1	165.9
February	216.5	8.5	0.1	165.9
March	216.5	8.5	0.2	165.9
April	283.1	13.0	0.3	260.4
May	216.3	8.5	0.3	165.9
June	216.0	8.5	0.7	165.9
July	216.0	8.5	0.7	165.9
August	216.0	8.5	0.7	165.9
September	283.0	13.0	0.4	260.4
October	283.1	13.0	0.3	260.4
November	216.5	8.5	0.2	165.9
December	216.5	8.5	0.1	165.9

[a]Number of beef cattle defecating in stream during each month.

4.1.2.b. Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 4.8) defecating in the stream where they have stream access. In order to have stream access, a pasture area must be contiguous to the stream and the owner of the cattle must not have fenced them away from the stream. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed is 7,360 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is 1.11×10^{10} cfu/day. Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.1.2.c. Direct Manure Deposition on Pastures

Beef cattle that graze on pastures (Table 4.8) but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of beef cattle on pasture by the amount of manure produced per day. The total amount of manure produced by the cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure.

Pasture 1 and pasture 2 have average annual cattle manure loadings of 2,351 and 526.8 lb/ac-year, respectively. The loadings vary because of differences in the number of cattle utilizing a given pasture type in the watershed, and because the extent of the pasture actively being grazed differs between pasture type. Fecal coliform loadings from beef on a daily basis, averaged over the year, are 3.57×10^9 and 8.30×10^8 cfu/ac-day for pastures 1 and 2, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

4.1.3. Wildlife

Wildlife fecal coliform contributions can be from excretion of waste on land and from direct deposition into streams. Information provided by VADGIF, professional trappers, and watershed residents were used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, duck, and goose. Populations for each species and fecal coliform amounts were determined (Table 4.3) along with preferred habitat and habitat area (Table 4.9).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams based upon their habitat (Table 4.9). Fecal matter produced by deer that is not directly deposited in streams, is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures, etc.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on pasture and forest acreage in the sub-watershed and as a fraction of pasture plus forest area in the entire watershed. Also, further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 ft buffer around streams and impoundments determined the muskrat population and distribution. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 4.10.

Table 4.9. Wildlife habitat description and acreage, and percent direct fecal deposition in streams for Abrams Creek.

Wildlife type	Habitat	Acres of habitat	Population Density (animal/ac-habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	12,285	0.047	1
Raccoon	600 ft buffer around streams and impoundments	3,412	0.07	10
Muskrat	66 ft buffer around streams and impoundments in forest and cropland	137	2.75	25
Beaver	300 ft buffer streams and impoundments in forest and pasture	912	0.015	50
Goose[b]	300 ft buffer around main streams	1,434	1.74 – off season 3.49 – peak season	1
Duck[a]	300 ft buffer around main streams	1,434	0.0624 – off season 0.0936 – peak season	1
Wild Turkey	Entire	6,023	0.01	1

	Watershed except urban and farmstead			

[a]Based on estimates provided by Professional Trapper (R. Spiggle, personal communication, October 2001, Blacksburg, VA.)
[b]The population for geese was estimated to be 5000 for the peak season and 2500 for the off season according to input from watershed residents at the first public meeting.

Table 4.10. Distribution of wildlife among Abrams Creek sub-watersheds.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Geese	Duck	Wild Turkey
ABR-01	4	5	19	0	112	3	1
ABR-02	41	35	68	2	709	19	6
ABR-03	18	18	32	2	336	9	3
ABR-04	14	17	43	1	336	9	2
ABR-05	8	7	19	1	187	5	1
ABR-06	49	19	41	1	447	12	2
ABR-07	78	43	78	2	709	19	6
ABR-08	55	16	8	0	335	9	1
ABR-09	100	31	16	0	634	17	5
ABR-10	129	46	36	3	671	18	23
ABR-11	77	28	15	1	485	13	11
Total	574	265	376	14	4961	134	60

4.1.4. Summary: Abrams Creek Fecal Coliform Sources

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories and is given in Table 4.11. Distribution of annual fecal coliform loading from nonpoint sources among different land use categories is also given in Table 4.11.

Table 4.11 shows that nonpoint source loadings to the land surface are approximately 500 times larger than direct loadings to the streams, with pastures and residential land uses receiving about 33 and 28% of the total fecal coliform load, respectively. One could prematurely assume that most of the fecal coliform loading in streams originates from upland sources. However, other factors such as precipitation amount and pattern, manure deposition time, location (proximity to streams), and bacteria die-off also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 5.

Table 4.11. Annual fecal coliform loadings to the stream and the various land use categories in the Abrams Creek watershed.

Source	Fecal coliform loading ($x10^{13}$ cfu/year)	Percent of total loading (%)
Direct loading to streams		
Cattle in stream	0.4	<0.1%
Wildlife in stream	1.3	0.1
Loading to pervious surfaces		
Cropland	0.7	0.1
Pasture 1	283	32.1
Pasture 2	12.1	1.4
Loafing Lots	228	25.9
Residential[a]	247	28.0
Forest	109	12.4
Total	*882*	--

[a]Includes loads received from Urban and High and Low Density Residential land uses due to failed septic systems and pets.

4.2. Upper Opequon Sources

A brief synopsis of the fecal coliform sources characterized and accounted for in the Upper Opequon Creek watershed, along with average fecal coliform production rates are shown in Table 4.12.

Table 4.12. Potential fecal coliform sources and daily fecal coliform production by source in Upper Opequon watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times10^6$ cfu/head-day)
Humans	21,631	1,950[a]

Beef cattle (pairs)	1,060	33,000[b]
Pets	8,326	450[c]
Deer	1,735	347[d]
Raccoon	990	113[d]
Muskrat	1,843	25[d]
Beaver	90	0.3[e]
Wild Turkey	317	93[f]
Duck	473	2,430[f]
Goose	551	799[d]

[a]Source: Geldreich *et al*. (1978)
[b]Based on ASAE (1998) fecal coliform production ratio of beef cattle to milk cow and fecal coliform produced by a milk cow
[c]Source: Weiskel *et al*. (1996)
[d]Source: Yagow (2001)
[e]Source: MapTech, Inc. (2000)
[f]Source: ASAE (1998)

4.2.1. Humans and Pets

The Upper Opequon watershed has an estimated population of 21,631 people (8,326 households at an average of 2.60 people per household; actual people per household varies among sub-watersheds). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

4.2.1.a. Failing Septic Systems

Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed that no die-off occurred once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters. Households were located using E-911 digital data from Frederick and Clarke counties, (see Glossary) . Each unsewered household was classified into one of three age categories (pre-1967, 1967-1987, and post-1987) based on USGS 7.5-min. topographic maps which were initially created using 1967 photographs and were photo-revised in 1987. Professional judgment was applied in assuming that septic system failure rates for houses in the pre-1967, 1967-1987, and post-1987 age categories were 40, 20, and 3%, respectively (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, VA.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate ranged from 2.3 to 2.8 persons per household based on the 2000 Census) by the per capita fecal coliform production rate of 1.95×10^{9} cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 2.3 persons/household was 4.49×10^{9} cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.13.

4.2.1.b. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1967 and 1967-1987 age categories, 10%, and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, it was estimated that there are no straight pipes in the watershed.

4.2.1.c. Pets

Assuming one pet per household, there are 8,326 pets in Upper Opequon watershed. A dog produces fecal coliform at a rate of 0.45×10^{9} cfu/day (Weiskel *et al.*, 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table 4.13. Pet waste is generated in the rural residential and urban residential land use types. Fecal coliform loading to streams from pet waste can result from surface runoff transporting fecal coliform from residential areas.

Table 4.13. Estimated number of unsewered houses by age category, number of failing septic systems, and pet population in Upper Opequon watershed.

Subwatershed	Unsewered houses in each age category (no.)[a]			Failing septic systems (no.)	Pet population[b]
	Pre-1967	1967-1987	Post-1987		
B08-01	0	3	1	1	5
B08-02	5	8	11	4	29
B08-03	0	0	0	0	571
B08-04	0	0	4	0	19

B08-05	26	19	33	15	78
B08-06	6	9	14	5	312
B08-07	12	11	3	7	534
B08-08	23	4	24	11	51
B08-09	73	24	37	35	883
B08-10	69	35	80	37	184
B08-11	16	18	38	11	137
B08-12	160	55	53	77	1906
B08-13	58	20	48	29	1323
B08-14	2	0	3	1	1526
B08-15	47	184	105	59	385
B08-16	78	104	201	58	383
Total	*575*	*494*	*655*	*348*	*8,326*

[a]No households were estimated to have a straight pipe, and 6,602 households were sewered. Adding these numbers to the numbers above yields the total number of households, 8,326.
[b]Assumed an average of one unit pet per household. Includes pets from sewered households.

4.2.2. Cattle

In the Upper Opequon Creek watershed, fecal coliform from beef cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from collected waste applied to crop and hay land. Beef cattle numbers in the Upper Opequon Creek watershed were estimated by communicating with NRCS, VADCR, VCE, and local producers. There are no dairies in the watershed.

4.2.2.a. Distribution of Beef Cattle in the Upper Opequon Watershed

The beef population was distributed among the sub-watersheds based on the location of the operations (Table 4.14). On average there are approximately 1,060 pairs (cow/calf) in the Upper Opequon Creek watershed on a daily basis. The actual number of beef cattle varies throughout the year due to the presence and absence of calves.

Table 4.14. Distribution of beef cattle among Upper Opequon Creek sub-watersheds.

Sub-watershed	Beef cattle (pairs)
B08-01	0
B08-02	0
B08-03	0
B08-04	0
B08-05	0
B08-06	20
B08-07	0
B08-08	0
B08-09	100

B08-10	100
B08-11	0
B08-12	0
B08-13	0
B08-14	0
B08-15	446
B08-16	394
Total	1060

Cattle spend varying amounts of time in streams, pasture, and confinement depending on the time of year. Accordingly, the proportion of fecal coliform deposited on any given land area varies throughout the year. The following assumptions were used to estimate the distribution of cattle and their manure:

a) Pasture 1 (improved pasture/hayland) will support twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which supports twice as many cows per unit area as pasture 3 (overgrazed pasture);

b) Cows on pastures that are contiguous to streams have stream access; because of the the location of beef farms within the creek, 100% of cows are assumed to have stream access in the watershed;

c) Cows with stream access spend varying amounts of time in and around the stream during different seasons (Table 4.16). Cows spend more time in and around the stream during the three summer months to protect their hooves from hornflies, among other reasons; and

d) Ten percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 90% of the manure is deposited on pasture area adjacent to the stream.

Table 4.15. Time spent by cattle in confinement and in the stream.

Month	Time spent in confinement (%)	Time spent in the stream (hours/day)[a]
January	40	0.50
February	40	0.50
March	0	0.75
April	0	1.00
May	0	1.50
June	0	3.50
July	0	3.50
August	0	3.50

September	0	1.50
October	0	1.00
November	0	0.75
December	40	0.50

[a]Time spent in and around the stream by cows that have stream access.

A sample calculation for determining the distribution of cattle between different land use types and the stream in sub-watershed B09-06 (Lower Opequon Creek) is shown in Appendix C. The resulting numbers of cattle in each land use type as well as in the stream for all sub-watersheds are given in Table 4.17 for beef cattle.

Table 4.16. Distribution of the beef cattle population (pairs) in Upper Opequon Creek Watershed.

Months	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[a]	Loafing
January	491.0	684.6	36.4	0.2	1.5	13.8
February	558.5	778.5	41.2	0.2	1.7	16.2
March	0.0	1331.4	70.4	0.4	4.3	27.8
April	0.0	1249.2	63.2	0.4	5.4	28.6
May	0.0	1185.8	61.9	0.5	7.7	29.4
June	0.0	1203.0	62.8	0.5	18.3	30.2
July	0.0	1230.0	64.1	0.5	18.7	31.0
August	0.0	1256.7	65.3	0.5	19.1	31.8
September	0.0	1107.1	59.7	0.5	7.1	32.6
October	0.0	983.2	52.3	0.3	4.3	20.0
November	0.0	1033.4	54.9	0.3	3.3	21.0
December	468.2	652.7	34.8	0.2	1.4	13.2

[a]Number of beef cattle defecating in stream.

4.2.2.b. Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 4.17) defecating in the stream. However, only cattle on pastures contiguous to streams have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading to the watershed directly deposited by cattle in the stream is 170,165 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is 2.56×10^{11} cfu/day. Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.2.2.c. Direct Manure Deposition on Pastures

Beef cattle that graze on pastures (Table 4.17) but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also change with season.

Pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 1,567; 508; and 222 lb/ac-year, respectively. The loadings vary because of differences in the number of cattle utilizing a given pasture type in the watershed, and because the extent of the pasture actively being grazed differs between pasture type. Fecal coliform loadings from beef on a daily basis, averaged over the year, are 2.38×10^9, 7.87×10^8 and 3.57×10^8 cfu/ac-day for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

4.2.2.d. Land Application of Solid Manure

Solid manure produced by beef cattle during confinement is collected for land application. The amount of solid manure produced in each sub-watershed was estimated based on the populations of beef cattle in the sub-watershed (Table 4.15) and their confinement schedules (Table 4.16). Typical beef cattle manure production numbers and fecal coliform densities are shown in Table 4.17.

Table 4.17. Estimated population of beef cattle, typical weights, per pair solid manure production, fecal coliform concentration in fresh solid manure.

Type of cattle	Population	Typical weight per pair (lb)	Solid manure produced (lb/pair-day)	Fecal coliform concentration in fresh manure ($\times 10^8$ cfu/lb)
Beef (pairs)	1,060	1,200	72.0[b]	5.5

[a]Based on input from local producers
[b]Source: MWPS (1993)
[c]Based on per capita fecal coliform and manure production.

Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. Solid manure is only applied to cropland during February through May, and the months of October and November. Solid manure can be applied to pasture during the whole year, except December and January. The monthly application schedule for solid manure is given in Table 4.19. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid cattle manure was applied to 114 acres (5.7%) of the cropland.

Table 4.18. Schedule of solid manure application in Upper Opequon watershed.

Month	Solid manure (%)[a]
January	0
February	5
March	25
April	20
May	5
June	5
July	5
August	5
September	10
October	10
November	10
December	0

[a]As percent of annual production.

4.2.3. Wildlife

Wildlife fecal coliform contributions can come from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, professional trappers, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, ducks, and geese. Populations for each species and fecal coliform amounts were determined (Table 4.12) along with preferred habitat and habitat area (Table 4.19).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams based upon their habitat (Table 4.19). Fecal matter produced by deer that is not directly deposited in streams, is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on pasture and forest acreage in the sub-watershed and as a fraction of pasture plus forest area in the entire watershed. Also, further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 ft buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 4.20.

Table 4.19. Wildlife habitat description and acreage, and percent direct fecal deposition in streams.

Wildlife type	Habitat	Acres of habitat	Population Density (animal/ac-habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	36,905	0.047	1
Raccoon	600 ft buffer around streams and impoundments	14,148	0.07	10
Muskrat	66 ft buffer around streams and impoundments in forest and cropland	670	2.75	25
Beaver	300 ft buffer streams and impoundments in forest and pasture	6,014	0.015	50
Geese[a]	300 ft buffer around main	5,049	0.078 – off season 0.1092 – peak	1

	streams		season	
Wood Duck[a]	300 ft buffer around main streams	5,049	0.0624 – off season 0.0936 – peak season	1
Wild Turkey	Entire Watershed except urban and farmstead	31,852	0.01	1

[a]Based on estimates provided by Professional Trapper (R. Spiggle, personal communication, October 2001, Blacksburg, VA.)

Table 4.20. Distribution of wildlife among sub-watersheds.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Goose	Duck	Wild Turkey
B08-01	2	2	12	0	2	2	0
B08-02	28	14	56	1	8	7	6
B08-03	43	33	102	3	22	19	7
B08-04	8	10	49	1	6	5	2
B08-05	73	44	54	5	31	27	15
B08-06	58	47	111	5	32	27	11
B08-07	110	52	113	4	21	18	16
B08-08	83	51	120	5	25	22	17
B08-09	162	106	180	8	42	36	25
B08-10	148	121	245	12	74	63	30
B08-11	75	69	125	7	19	16	15
B08-12	194	130	221	11	62	53	34
B08-13	213	123	248	11	77	66	37
B08-14	78	47	91	4	34	29	10
B08-15	220	56	35	6	37	32	44
B08-16	240	84	81	8	59	51	48
Total	*1735*	*990*	*1843*	*90*	*551*	*473*	*317*

4.2.4. Summary: Contribution from All Sources

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories and is given in Table 4.21. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 4.21.

From Table 4.21, it is clear that nonpoint source loadings to the land surface are more than 150 times larger than direct loadings to the streams (not including commercial sources), with pastures receiving about 82% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation amount and pattern, manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Section 5.1.

Table 4.21. Annual fecal coliform loadings to the stream and the various land use categories in the Upper Opequon watershed.

Source	Fecal coliform loading ($x10^{13}$ cfu/year)	Percent of total loading (%)
Direct loading to streams		
Cattle in stream	9.36	<0.1
Wildlife in stream	1.32	<0.1
Loading to land surfaces		
Cropland	9.23	<0.1
Pasture 1	1290	77.2
Pasture 2	69.0	4.1
Pasture 3	0.485	<0.1
Loafing Lots	29.7	1.8
Residential[a]	203	12.2
Forest	58.3	3.5
Total	*1670*	--

[a]Includes loads received from both High and Low Density Residential and Farmstead due to failed septic systems and pets.

4.3. Lower Opequon Sources

A synopsis of the fecal coliform sources characterized and accounted for in the Lower Opequon Creek watershed remnant along with average fecal coliform production rates are shown in Table 4.22.

Table 4.22. Potential fecal coliform sources and daily fecal coliform production by source in Lower Opequon watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	9,082	1,950[a]
Dairy cattle		
Milk and dry cows	1,030	20,000[b]
Heifers [c]	915	9,200[d]
Beef cattle (pairs)	872	33,000[e]
Pets	3,512	450[f]
Deer	1,908	347[g]
Raccoon	836	113[g]
Muskrat	1,694	25[g]
Beaver	81	0.3[h]
Wild Turkey	367	93[i]
Duck	494	2,430[i]
Goose	577	799[g]

[a]Source: Geldreich *et al*. (1978)
[b]Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c]Includes calves
[d]Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow
[e]Based on ASAE (1998) fecal coliform production ratio of beef cattle to milk cow and fecal coliform produced by a milk cow
[f]Source: Weiskel *et al*. (1996)
[g]Source: Yagow (2001)
[h]Source: MapTech, Inc. (2000)
iSource: ASAE (1998)

4.3.1. Humans and Pets

The Lower Opequon watershed has an estimated population of 9,082 people (3,512 households) at an average of 2.59 people per household; actual people per household varies among sub-watersheds). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

4.3.1.a. Failing Septic Systems

Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed that no die-off occurred once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters. Households were located data obtained from the Frederick and Clarke County Planning Department. Each unsewered household was classified into one of three age categories (pre-1967, 1967-1987, and post-1987) based on USGS 7.5-min. topographic maps which were initially created using 1967 photographs and were photo-revised in 1987. Professional judgment was applied in assuming that septic system failure rates for houses in the pre-1967, 1967-1987, and post-1987 age categories were 40, 20, and 3%, respectively (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, VA.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that subwatershed (occupancy rate ranged from 2.39 to 2.81 persons per household, 2000 Census) by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich *et al*., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.39 persons/household was 4.66×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.23.

4.3.1.b. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1967 and 1967-1987 age categories, 10%, and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, VA.). Based on these criteria, it was estimated that there are no straight pipes in the watershed.

4.3.1.c. Pets

Assuming one pet per household, there are 3,512 pets in Lower Opequon watershed. A dog produces fecal coliform at a rate of 0.45×10^9 cfu/day (Weiskel *et al.*, 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table 4.23. Pet waste is generated in the rural residential and urban residential land use types. Fecal coliform loading to streams from pet waste can result from surface runoff transporting fecal coliform from residential areas.

Table 4.23. Estimated number of unsewered houses by age category, number of failing septic systems, and pet population in Lower Opequon watershed remnant.

Subwatershed	Unsewered houses in each age category (no.)[a]			Failing septic systems (no.)	Pet population[b]
	Pre-1967	1967-1987	Post-1987		
B09-01	73	24	73	36	207
B09-02	17	14	29	10	60
B09-03	47	32	87	28	166
B09-04	16	11	17	9	44
B09-05	50	22	45	26	117
B09-06	57	42	119	35	372
B09-07	67	20	78	33	204
B09-08	36	17	37	19	286
B09-09	40	107	138	42	294
B09-10	39	44	83	27	166
B09-11	127	129	122	80	378
B09-12	4	4	4	3	12
B09-13	35	32	86	23	1,199
B09-14	0	3	4	1	7
Total	*608*	*501*	*922*	*371*	*3,512*

[a]No households were estimated to have straight pipes, and 1,481 households were sewered. Adding these numbers to the numbers above yields the total number of households, 3,512.
[b]Assumed an average of one pet per household. Includes pets from sewered households.

4.3.2. Cattle

In the Lower Opequon Creek watershed remnant, fecal coliform from cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Cattle numbers in the Lower Opequon Creek watershed remnant were estimated by communicating with NRCS, VADCR, VCE, VDACS, and local producers.

4.3.2.a. Distribution of Dairy and Beef Cattle in the Lower Opequon Watershed

There are four dairy farms in the watershed, based on information obtained from visual observation of the watershed and from the Virginia Department of Agricultural and Consumer Services (VDACS). Based on communication with local dairy farmers, it was determined that there are 910 milk cows, 120 dry cows, and 915 heifers in the watershed. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farms (Table 4.24). Beef cattle in the watershed (872 pairs) included cow/calf and feeder operations.

Table 4.24. Distribution of dairy cattle, dairy operations and beef cattle among sub-watersheds.

Sub-watershed	Dairy cattle	No. of dairy operations	Beef cattle (pairs)
B09-01	430	1	125
B09-02	0	0	0
B09-03	0	0	0
B09-04	965	2	250
B09-05	0	0	0
B09-06	550	1	237
B09-07	0	0	0
B09-08	0	0	60
B09-09	0	0	0
B09-10	0	0	0
B09-11	0	0	200
B09-12	0	0	0
B09-13	0	0	0
B09-14	0	0	0
Total	*1945*	*4*	*872*

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Based on discussions with NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (thus their manure) among different land use types and in the stream.

a) Cows are confined according to the schedule given in Table 4.25.

b) When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.

c) Pasture 1 (improved pasture/hayland) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).

d) Cows on pastures that are contiguous to streams have stream access; because of the incised nature of the channel in Lower Opequon Creek and because most of the cattle are fenced out of the stream, only 5% of the cows in the watershed are assumed to have stream access.

e) Cows with stream access spend varying amounts of time in the stream during different seasons (Table 4.25). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.

f) Ten percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 90% of the manure is deposited on pastures.

Table 4.25. Time spent by cattle in confinement and in the stream.

Month	Time spent in confinement (%)		Time spent in the stream (hours/day)[a]
	Milk cows	Dry cows, heifers, and beef cattle	
January	75%	40%	0.50
February	40%	40%	0.50
March	30%	0%	0.75
April	30%	0%	1.00
May	30%	0%	1.50
June	30%	0%	3.50
July	30%	0%	3.50
August	30%	0%	3.50
September	30%	0%	1.50
October	75%	0%	1.00
November	40%	0%	0.75
December	75%	40%	0.50

[a]Time spent in and around the stream by cows that have stream access.

A sample calculation for determining the dairy cattle distribution among different land use types and the stream in sub-watershed B09-06 is shown in Appendix C. The resulting numbers of cattle in each land use type as well as in the stream for all sub-watersheds are given in Table 4.26 for dairy cattle and in Table 4.27 for beef cattle.

Table 4.26. Distribution of the dairy cattle[a] population in the Lower Opequon Creek Watershed Remnant.

Months	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	1136.50	875.54	19.14	1.22	0.09	12.50
February	1136.50	875.54	19.14	1.22	0.09	12.50
March	364.00	1613.45	35.06	2.23	0.26	30.00
April	273.00	1697.52	36.78	2.34	0.36	35.00
May	273.00	1697.34	36.78	2.34	0.54	35.00
June	273.00	1696.63	36.76	2.34	1.27	35.00
July	273.00	1696.63	36.76	2.34	1.27	35.00
August	273.00	1696.63	36.76	2.34	1.27	35.00
September	273.00	1697.34	36.78	2.34	0.54	35.00
October	273.00	1697.52	36.78	2.34	0.36	35.00
November	364.00	1613.45	35.06	2.23	0.26	30.00
December	1136.50	875.54	19.14	1.22	0.09	12.50

[a]Includes milk cows, dry cows, and heifers.
[b]Number of dairy cattle defecating in stream.
[c]Milk cows in loafing lot.

Table 4.27. Distribution of the beef cattle population (pairs) in the Lower Opequon Creek Watershed Remnant.

Months	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[a]	Loafing
January	432.30	593.73	20.75	1.07	0.19	32.71
February	487.66	667.96	23.67	1.25	0.22	38.39
March	0.00	1020.32	37.37	2.15	0.50	65.89
April	0.00	1041.08	38.26	2.21	0.68	67.78
May	0.00	1061.67	39.13	2.27	1.04	69.68
June	0.00	1110.26	40.77	2.33	2.53	71.57
July	0.00	1135.82	41.78	2.39	2.59	73.47
August	0.00	1161.96	42.81	2.46	2.65	75.37

September	0.00	1225.50	44.83	2.52	1.19	77.26
October	0.00	873.47	30.41	1.55	0.57	47.40
November	0.00	912.01	31.80	1.62	0.44	49.77
December	415.40	570.69	19.92	1.02	0.18	31.28

[a]Number of beef cattle defecating in stream.

4.3.2.b. Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 4.26) and beef cattle (Table 4.27) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed is 37,349 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is 4.44×10^{10} cfu/day. Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.3.2.c. Direct Manure Deposition on Pastures

Dairy (Table 4.26) and beef (Table 4.27) cattle that graze on pastures but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also change with season.

Pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 2,900; 763; and 766 lb/ac-year, respectively. The loadings vary because stocking rate varies with pasture type. Fecal coliform loadings from cattle on a daily basis, averaged over the year, are 2.80×10^9, 8.37×10^8, and 8.23×10^8 cfu/ac-day for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

4.3.2.d. Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule (Table 4.25) and the number of milk cows (Section 4.3.2.a), annual liquid dairy manure production in the watershed is 2.4 million gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 1.18×10^9 cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) in application to land. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture land use categories (VADCR, 1999), respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 366 acres (11.1%) of cropland. Because there was insufficient liquid dairy manure for cropland, no liquid dairy manure was applied to pasture.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (VADCR, 1999). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn, and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye, and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (VADCR, 1999) is given in Table 4.28. Dry cows and heifers were assumed to produce only solid manure.

Table 4.28. Schedule of cattle waste application in Lower Opequon watershed.

Month	Liquid manure applied (%)[a]	Solid manure applied (%)[a]
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	10	5
July	0	5
August	5	5
September	15	10
October	5	10
November	10	10
December	0	0

[a]As percent of annual production.

4.3.2.e. Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4.29. Solid Manure is the last on the priority list for application to land (it falls behind liquid manure). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed (Table 4.24) and their confinement schedules (Table 4.25). Solid manure from dry cows, heifers, and beef cattle contained different fecal coliform concentrations (cfu/lb) (Table 4.29). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 4.29).

Table 4.29. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, fecal coliform concentration in fresh solid manure in individual cattle type, and weighted average fecal coliform concentration in fresh solid manure

Type of	Population	Typical	Solid manure	Fecal	Weighted

cattle		weight (lb)	produced (lb/animal-day)	coliform concentration in fresh manure (× 10^6 cfu/lb)	average fecal coliform concentration in fresh manure (× 10^6 cfu/lb)
Dry cow	120	1,400[a]	120.0[b]	167[c]	302
Heifer	915	640[d]	40.7[a]	226[c]	
Beef (pairs)	872	1,000[e]	60.0[b]	430[c]	

[a]Source: ASAE (1998)
[b]Source: MWPS (1993)
[c]Based on per capita fecal coliform production per day and manure production
[d]Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).
[e]Based on input from local producers

Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May, and the months of October and November. Solid manure can be applied to pasture during the whole year, except during December and January. The method of application of solid manure to cropland or pasture is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 4.28. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 183 acres (5.5%) of the cropland. Because there was insufficient solid manure for cropland, solid manure was not applied on pasture 1, pasture 2, or pasture 3.

4.3.3. Wildlife

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, professional trappers, and watershed residents were used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 4.22) along with preferred habitat and habitat area (Table 4.30).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams based upon their habitat (Table 4.30). Fecal matter produced by deer that is not directly deposited in streams, is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on pasture and forest acreage in the sub-watershed and as a fraction of pasture plus forest area in the entire watershed. Also, further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 ft buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 4.31.

Table 4.30. Wildlife habitat description and acreage, and percent direct fecal deposition in streams.

Wildlife type	Habitat	Acres of habitat	Population Density (animal/ac-habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	52,873	0.047	0.1
Raccoon	600 ft buffer around streams and impoundments	15,327	0.07	10
Muskrat	66 ft buffer around streams and impoundments in forest and cropland	762	2.75	25
Beaver	300 ft buffer streams and impoundments in forest and pasture	6,289	0.015	50
Geese[a]	300 ft buffer around main streams	6,730	0.078 – off season 0.1092 – peak season	2
Wood Duck[a]	300 ft buffer around main streams	6,730	0.0624 – off season 0.0936 – peak season	2

Wild Turkey	Entire Watershed except urban and farmstead	43,292	0.01	1

[a]Based on estimates provided by Professional Trapper (R. Spiggle, personal communication, October 2001, Blacksburg, VA.)

Table 4.31. Distribution of wildlife among sub-watersheds.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
B09-01	184	105	282	11	68	59	37
B09-02	70	38	35	4	27	23	15
B09-03	216	54	56	5	34	29	44
B09-04	69	29	26	3	23	20	14
B09-05	76	51	144	5	35	30	15
B09-06	252	85	124	7	52	45	46
B09-07	93	52	185	6	37	32	19
B09-08	171	86	213	9	68	58	34
B09-09	162	43	57	3	31	26	31
B09-10	71	58	183	6	40	34	13
B09-11	319	136	181	13	86	73	65
B09-12	6	7	33	1	6	5	1
B09-13	212	87	152	7	65	56	31
B09-14	8	5	24	1	4	3	2
Total	1,908	836	1,694	81	577	494	367

4.3.4. Summary: Contribution from All Sources

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories and is given in Table 4.32. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 4.32.

From Table 4.32, it is clear that nonpoint source loadings to the land surface are 700 times larger than direct loadings to the streams (not including commercial sources), with pastures receiving about 87% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation amount and pattern, manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 5.

Table 4.32. Annual fecal coliform loadings to the stream and the various land use categories in the Lower Opequon watershed.

Source	Fecal coliform loading (x10^{13} cfu/year)	Percent of total loading (%)
Direct loading to streams		
Cattle in stream	1.6	<0.1
Wildlife in stream	1.8	<0.1
Loading to land surfaces		
Cropland	20.5	<0.1
Pasture 1	2070	84.5
Pasture 2	62.2	2.5
Pasture 3	3.6	<0.1
Loafing Lots	96.6	3.9
Residential[a]	130	5.3
Forest	59.2	2.4
Total	*2450*	--

[a]Includes loads received from both High and Low Density Residential and Farmstead due to failed septic systems and pets.

CHAPTER 5: MODELING PROCESS FOR FECAL COLIFORM TMDL DEVELOPMENT

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the water body of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, modeling process, input data requirements, model calibration procedure and results, and model validation results are discussed.

5.1. Model Description

Conducting and TMDL study requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN, Windows Version (WinHSPF) (Duda *et al*., 2001) was used to model fecal coliform transport and fate in the Abrams Creek and Upper and Lower Opequon Creek watersheds. The ArcGIS 8.2 and ArcView 3.1 GIS programs were used to display and analyze landscape information.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Duda *et al*., 2001). HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within RCHRES module. Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent pollutant model (GQUAL) in HSPF.

5.2. Selection of Sub-watersheds

5.2.1. Abrams Creek Sub-watersheds

Abrams Creek is a moderately sized watershed (12,285 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into eleven sub-watersheds as shown in Figure 5.1. Tributaries to the impaired segment (Abrams Creek ABR-1,3,5,7,9,10) include Hollow Run (ABR-2), Town Run (ABR-8,11) and two unnamed tributaries (ABR-4,6). The stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment. Because loadings of fecal coliform are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use. The sub-watersheds ABR-3 and ABR-5 were delineated to preserve the stream network of the watershed and result in much smaller sub-watersheds relative to the other sub-watersheds.

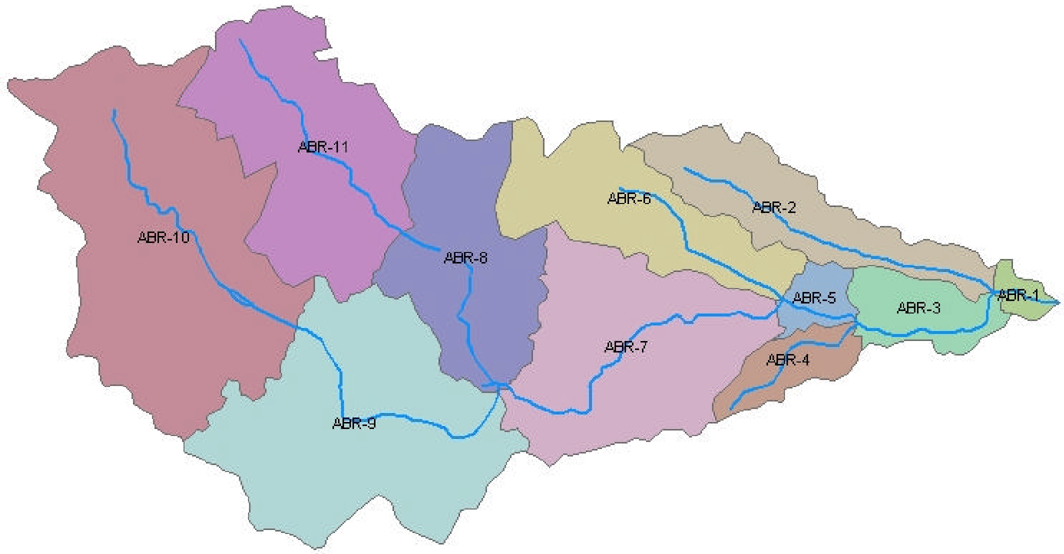

Figure 5.1. Abrams Creek Sub-watersheds.

5.2.2. Upper Opequon Sub-watersheds

Upper Opequon is a moderately sized watershed (36,905 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into sixteen sub-watersheds as shown in Figure 5.2. Tributaries to the impaired segment (Upper Opequon Creek B08-1, 2,4,6,8,10,11,13,15,16) include Isaac Run (B08-05), Sulfur Spring Run (B08-07), Buffalo Lick Run (B08-09), Wrights Run (B08-12), Hodge Run (located in B08-13), Stribling Run (located in B08-16), and 2 unnamed tributaries (B08-3,14). The stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment. Because loadings of fecal coliform are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use. The sub-watersheds B08-1, B08-2, and B08-4 were delineated to preserve the stream network of the watershed and result in much smaller sub-watersheds relative to the other sub-watersheds.

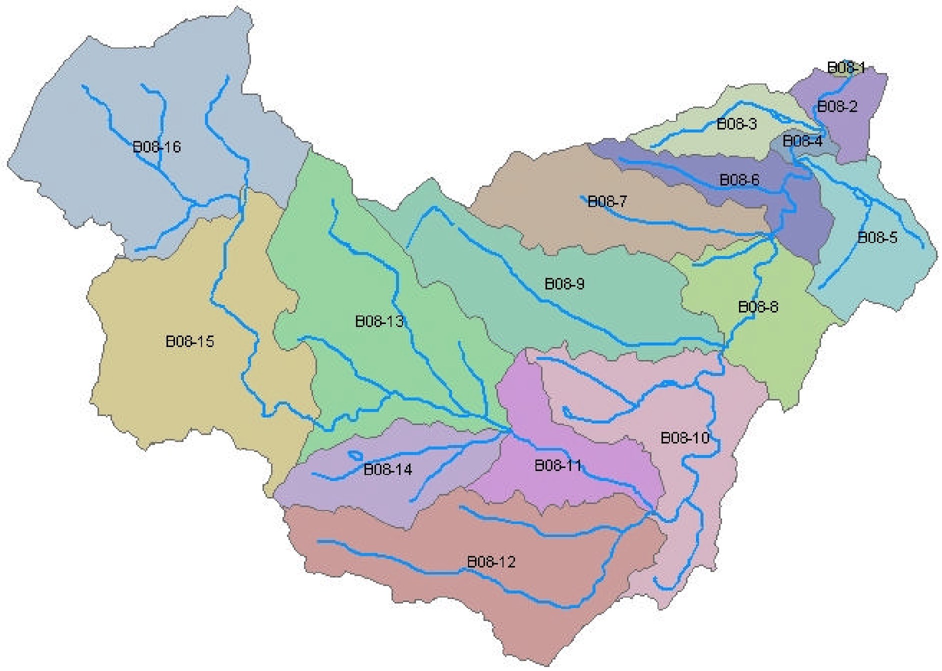

Figure 5.2. Upper Opequon Sub-watersheds.

5.2.3. Lower Opequon Sub-watersheds

Lower Opequon is a moderately sized watershed (52,873 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into fifteen sub-watersheds as shown in Figure 5.3. As shown in Figure 5.3, the Lower Opequon watershed includes the Abrams Creek watershed (B09-15). The description of the sub-watershed B09-15 was discussed in Section 5.2.1 and will not be repeated here. Abrams Creek is part of the Lower Opequon impaired segment. The remainder of the Lower Opequon (hereafter referred to as the Lower Opequon remnant) is 40,589 ac in size. The following description applies only to the Lower Opequon remnant. Tributaries to the impaired segment (B09-1,5,7,10,12,14) include Turkey Run (located in B09-1), Slate Run (located in B09-5), Clear Brook Run (B09-6), Haitt Run (B09-9), Dry Marsh Run (B09-11), Redbud Run (B09-13), and 4 unnamed tributaries (B09-2,3,4,8). The stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment. Because loadings of fecal coliform are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use. The sub-watersheds B09-12 and B09-14 were delineated to preserve the stream network of the watershed and result in much smaller sub-watersheds relative to the other sub-watersheds.

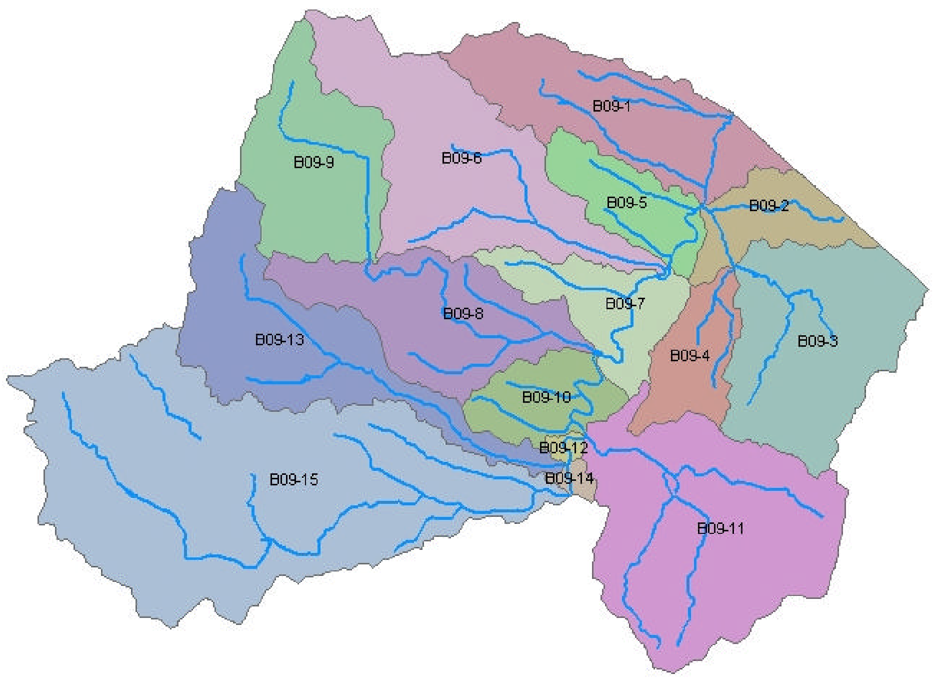

Figure 5.3. Lower Opequon Sub-watersheds.

5.3. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDL for the Abrams Creek, Upper Opequon Creek, and Lower Opequon Creek watersheds are discussed below.

5.3.1. Climatological Data

The climate data needed for the simulations conducted as a part of this study was accessed from the National Climatic Data Center (NCDC) (NCDC, 2003) or the National weather service (NWS). Hourly weather data needed to conduct the model simulations were taken from the Star Tannery weather station. This was the closest weather station to the watershed that collected hourly rainfall during the calibration and validation periods. Several discrepancies were found between the observed runoff and observed precipitation records, wherein a large storm would produce little to no runoff. The summed hourly precipitation for the day during these storm events was compared to the daily record at the Winchester station, located inside the watershed; if a discrepancy was found between the Star Tannery rainfall and that of the Winchester station, the Star Tannery precipitation was adjusted such that the sum of the hourly precipitation matched that of the Winchester station.

5.3.2. Hydrology Model Parameters

The hydrology parameters required by PWATER and IWATER were defined for every land use category for each sub-watershed. For each reach, a function table (FTABLE) is required to describe the relationship between water depth, surface area, volume, and discharge (Duda *et al*., 2001). These parameters were estimated by surveying representative channel cross-sections in each sub-watershed. Information on stream geometry in each sub-watershed for Abrams Creek, Upper Opequon Creek, and the Lower Opequon Creek remnant are presented in Table 5.1. Hydrology parameters required for the PWATER, IWATER, HYDR, and ADCALC sub-modules are listed in BASINS Version 3.0 User's Manual 3.0 (USEPA, 2001). Parameters required as inputs for PQUAL, IQUAL, and GQUAL are given in the BASINS Version 3.0 User's Manual (USEPA, 2001). Runoff estimated by the model is also an input to the water quality components. Values for the hydrology and water quality parameters were estimated based on local conditions when possible; otherwise the default parameters provided within HSPF were used

Table 5.1. Stream characteristics of Abrams Creek, Lower and Upper Opequon watersheds.

Watershed	Sub-watershed	Stream length (mile)	Average width (ft)	Average channel depth (ft)	Slope (ft/ft)
Abrams	ABR-01	0.55	20.00	1.00	0.0034
Abrams	ABR-02	2.73	7.00	0.50	0.0080
Abrams	ABR-03	1.35	22.50	1.00	0.0056
Abrams	ABR-04	1.36	3.75	0.30	0.0195
Abrams	ABR-05	0.64	13.00	0.65	0.0059
Abrams	ABR-06	1.68	20.00	1.00	0.0113
Abrams	ABR-07	2.87	17.67	1.83	0.0033
Abrams	ABR-08	1.84	7.20	0.67	0.0093
Abrams	ABR-09	2.47	16.00	1.14	0.0092
Abrams	ABR-10	2.56	7.00	0.75	0.0070
Abrams	ABR-11	1.56	8.00	0.40	0.0061
Upper Opequon	B08-01	0.26	88 5.87	30.35	0.0015
Upper Opequon	B08-02	0.99	88 5.87	30.35	0.0004
Upper Opequon	B08-03	2.62	771.04	36.91	0.0038
Upper Opequon	B08-04	0.80	504.45	25.43	0.0005
Upper Opequon	B08-05	2.68	771.04	36.91	0.0025
Upper Opequon	B08-06	1.89	2132.65	90.23	0.0004
Upper Opequon	B08-07	3.76	721.82	31.17	0.0030
Upper Opequon	B08-08	2.01	1985.01	82.85	0.0008
Upper Opequon	B08-09	4.23	672.61	23.79	0.0025
Upper Opequon	B08-10	3.77	1213.97	45.93	0.0005
Upper Opequon	B08-11	2.33	1008.91	64.80	0.0008
Upper Opequon	B08-12	5.42	738.23	36.09	0.0016
Upper Opequon	B08-13	3.21	844.86	38.55	0.0015
Upper Opequon	B08-14	2.54	750.53	36.09	0.0024
Upper Opequon	B08-15	4.23	836.66	14.76	0.0013
Upper Opequon	B08-16	3.06	1189.36	16.41	0.0017
Lower Opequon	B09-01	1.52	451.14	18.87	0.0013
Lower Opequon	B09-02	2.28	840.76	18.87	0.0080
Lower Opequon	B09-03	2.86	529.06	7.38	0.0037
Lower Opequon	B09-04	2.07	438.83	6.56	0.0054
Lower Opequon	B09-05	1.34	455.24	15.58	0.0060
Lower Opequon	B09-06	4.18	910.48	36.91	0.0091
Lower Opequon	B09-07	2.36	397.82	6.56	0.0012
Lower Opequon	B09-08	4.97	771.04	47.57	0.0085
Lower Opequon	B09-09	3.76	336.30	9.84	0.0049
Lower Opequon	B09-10	2.14	426.53	10.66	0.0025
Lower Opequon	B09-11	4.75	582.38	9.84	0.0049
Lower Opequon	B09-12	0.68	426.53	13.94	0.0053
Lower Opequon	B09-13	6.42	287.09	13.12	0.0089
Lower Opequon	B09-14	0.50	401.92	15.58	0.0031

5.4. Land use

5.4.1. Abrams Land Use

Using 1995-1997 aerial photographs, VADCR identified 23 land use types in the watershed. The land use types were verified by Virginia Tech in 2003. The 23 land use types were consolidated into eight categories based on similarities in hydrologic and waste application/production features (Table 5.2). The land use categories were assigned pervious/impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules. Some hydrology and water quality model parameters used in the PERLND and IMPLND modules are a function of land use.

Table 5.2. Consolidation of VADCR land use categories for Abrams Creek watershed.

TMDL Land Use Categories	Pervious/Impervious[a] (%)	VADCR Land Use Categories (Class No.)
Cropland	Pervious (100)	Rotational Hay (2114) Orchard (22) Cropland (211)
Pasture 1	Pervious (100)	Improved Pasture/Hayland (2121)
Pasture 2	Pervious (100)	Unimproved Pasture (2122) Grazed Woodland (461)
Loafing Lot	Pervious (100)	Cattle Operation (231)
Forest	Pervious (100)	Forested (4) Water (5) Harvested Forest Land (44) Unmanaged Grass / CRP (2432)
Low-density Residential (LDR)	Pervious (90) Impervious (10)	Farmstead (241) Wooded Residential (118) Open Urban (18) Mobile Homes (115) Mixed Urban (16) Low Density Residential (111)
High-density Residential (HDR)	Pervious (85) Impervious (15)	Medium Density Residential (112) High Density Residential (113) Barren (7)
Urban	Pervious (40) Impervious (60)	Commercial (12) Industrial (13) Transportation (14)

[a]Percent pervious/impervious information was used in modeling (described in Chapter 5)

As discussed in Section 5.2.1, eleven sub-watersheds were defined to spatially analyze waste or fecal coliform distribution within the watershed (Figure 5.1). Land use distribution in the sub-watersheds as well as in the entire Abrams Creek watershed is presented in Table 5.3.

Table 5.3. Land use distribution in Abrams Creek watershed (acres).

Sub-watersheds	Land Use								
	Cropland	Pasture 1	Pasture 2	Loafing Lots	Forest	LDR	HDR	Urban	Total
ABR-01	0.0	33.6	1.3	0	42.3	1.2	0.0	8.8	87.2
ABR-02	0.0	138.9	116.6	0	315.5	168.0	99.1	68.9	907.0
ABR-03	0.0	140.6	19.0	0	144.2	40.8	44.6	0.0	389.3
ABR-04	0.0	66.6	33.9	0	105.2	12.1	63.3	11.9	292.9
ABR-05	0.0	43.3	2.4	0	43.1	4.0	79.8	0.0	172.6
ABR-06	0.0	37.2	25.4	0	161.6	221.6	309.2	270.3	1,025.3
ABR-07	0.0	143.5	61.1	0	359.5	311.6	615.6	155.2	1,646.5
ABR-08	0.0	16.0	0	0	103.3	210.1	393.4	469.1	1,191.8
ABR-09	25.8	185.2	19.1	0	323.9	376.0	445.8	751.0	2,126.8
ABR-10	444.5	911.6	127.1	2.7	757.7	179.5	172.9	106.6	2,700.0
ABR-11	294.4	469.6	2.4	0	370.5	86.8	344.7	176.8	1,745.2
Total	764.7	2,186.2	408.3	2.7	2,726.7	1,611.7	2,568.5	2,018.7	12,284.7

5.4.2. Upper Opequon Land Use

Using 1995-1997 aerial photographs, VADCR identified 24 land use types in the watershed. The land use types were verified by Virginia Tech in 2003. The 24 land use types were consolidated into ten categories based on similarities in hydrologic and waste application/production features (Table 5.4). The land use categories were assigned pervious/impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules. Some hydrology and water quality model parameters used in the PERLND and IMPLND modules are a function of land use.

Table 5.4. Consolidation of VADCR land use categories for Upper Opequon watershed.

TMDL Land Use Categories	Pervious/Impervious (%)	VADCR Land Use Categories (Class No.)
Cropland	Pervious (100)	Rotational Hay (2114) Orchard (22) Cropland (211)
Pasture 1	Pervious (100)	Improved Pasture/Hayland (2121)
Pasture 2	Pervious (100)	Unimproved Pasture (2122) Grazed Woodland (461)
Pasture 3	Pervious (100)	Overgrazed (2123)
Loafing Lot	Pervious (100)	Cattle Operation (231)
Forest	Pervious (100)	Forested (4) Water (5) Harvested Forest Land (44) Unmanaged Grass / CRP (2432)
Farmstead	Pervious (90) Impervious (10)	Farmstead (241)
Low-density Residential (LDR)	Pervious (90) Impervious (10)	Wooded Residential (118) Open Urban (18) Mobile Homes (115) Mixed Urban (16) Low Density Residential (111)
High-density Residential (HDR)	Pervious (85) Impervious (15)	Medium Density Residential (112) High Density Residential (113) Barren (7)
Urban	Pervious (40) Impervious (60)	Commercial (12) Industrial (13) Transportation (14)

[a]Percent pervious/impervious information was used in modeling (described in Chapter 5)

As discussed in Section 5.2.2, sixteen sub-watersheds were defined to spatially analyze waste or fecal coliform distribution within the watershed (Figure 5.2). Land use distribution in the sub-watersheds as well as in the entire Upper Opequon Creek watershed is presented in Table 5.5.

Table 5.5. Land-use distribution in Upper Opequon watershed (acres).

	Land Use										
Subwatersheds	**Cropland**	**Pasture 1**	**Pasture 2**	**Pasture 3**	**Loafing Lot**	**Forest**	**Farmstead**	**LDR**	**HDR**	**Urban**	**Total**
B08-01	0.0	24.4	0.2	0.0	0.0	9.5	0.0	0.0	0.0	10.7	44.8
B08-02	23.2	336.6	19.3	0.0	0.0	202.2	0.7	3.5	0.0	16.3	601.8
B08-03	24.2	179.0	100.3	2.1	0.0	383.2	0.9	214.6	0.0	9.9	914.2
B08-04	0.0	67.7	11.1	0.0	0.0	86.0	0.8	3.0	0.0		168.7
B08-05	47.9	966.1	130.3	15.1	0.0	368.0	7.6	15.2	0.0	8.4	1,558.6
B08-06	4.5	525.0	51.6	9.0	0.0	509.6	9.4	114.8	0.0	8.8	1,232.6
B08-07	0.1	574.6	148.2	0.0	0.0	917.9	0.6	430.8	2.3	256.8	2,331.3
B08-08	76.5	594.5	336.6	9.9	0.0	670.3	6.0	6.0	0.0	72.2	1,772.0
B08-09	218.8	1,046.2	28.7	13.9	0.0	1,147.2	8.8	546.9	52.1	387.0	3,449.6
B08-10	348.1	1,442.9	359.2	3.5	2.7	877.0	17.5	55.5	0.0	35.4	3,141.9
B08-11	22.4	927.9	87.0	7.2	0.0	497.5	2.4	31.5	0.0	24.4	1,600.4
B08-12	126.5	1881.7	341.6	0.0	0.0	1,075.7	30.8	501.2	90.5	72.2	4,120.2
B08-13	330.5	1,707.7	272.9	6.9	0.0	1,373.4	20.5	364.7	30.1	428.1	4,534.7
B08-14	0.0	400.0	70.9	0.0	0.0	535.7	4.8	524.1	41.5	74.1	1651.2
B08-15	522.7	1,938.6	291.3	8.6	0.0	1,610.4	26.8	249.2	0.0	27.0	4,674.7
B08-16	242.1	2,550.5	122.3	0.0	0.0	1,839.5	17.6	258.8	0.0	77.5	5,108.3
Total	1,987.5	15,163.5	2,371.5	76.3	2.7	12,103.2	155.2	3,319.8	216.5	1,508.9	36,905.1

5.4.3. Lower Opequon Land Use

Using 1995-1997 aerial photographs, VADCR identified 24 land use types in the watershed. The land use types were verified by Virginia Tech in 2003. The 24 land use types were consolidated into ten categories based on similarities in hydrologic and waste application/production features (Table 5.6). The land use categories were assigned pervious/impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules. Some hydrology and water quality model parameters used in the PERLND and IMPLND modules are a function of land use.

Table 5.6. Consolidation of VADCR land use categories for Lower Opequon watershed.

TMDL Land Use Categories	Pervious/Impervious[a] (%)	VADCR Land Use Categories (Class No.)
Cropland	Pervious (100)	Rotational Hay (2114) Orchard (22) Cropland (211)
Pasture 1	Pervious (100)	Improved Pasture/Hayland (2121)
Pasture 2	Pervious (100)	Unimproved Pasture (2122) Grazed Woodland (461)
Pasture 3	Pervious (100)	Overgrazed (2123)
Loafing Lot	Pervious (100)	Cattle Operation (231)
Forest	Pervious (100)	Forested (4) Water (5) Harvested Forest Land (44) Unmanaged Grass / CRP (2432)
Farmstead	Pervious (90) Impervious (10)	Farmstead (241)
Low-density Residential	Pervious (90) Impervious (10)	Wooded Residential (118) Open Urban (18) Mobile Homes (115) Mixed Urban (16) Low Density Residential (111)
High-density Residential	Pervious (85) Impervious (15)	Medium Density Residential (112) High Density Residential (113) Barren (7)
Urban	Pervious (40) Impervious (60)	Commercial (12) Industrial (13) Transportation (14)

[a]Percent pervious/impervious information was used in modeling (described in Chapter 5)

As discussed in Section 5.2.3, fifteen sub-watersheds were defined to spatially analyze waste or fecal coliform distribution within the watershed (Figure 5.3). Again sub-watershed B90-15 is the Abrams Creek watershed described in Section 5.4.1. Land use distribution in the 14 sub-watersheds as well as in the entire Lower Opequon Creek remnant is presented in Table 5.7.

Table 5.7. Land-use distribution in Lower Opequon watershed remnant (acres).

	Land Use										
Subwatersheds	**Cropland**	**Pasture 1**	**Pasture 2**	**Pasture 3**	**Loafing Lot**	**Forest**	**Farmstead**	**LDR**	**HDR**	**Urban**	**Total**
B09-01	299.3	2,102.1	119.7	1.7	0.0	1,217.9	19.9	109.5	0.0	37.0	3907.1
B09-02	60.2	802.6	160.0	0.0	0.0	456.2	5.5	13.4	0.0	0.0	1497.8
B09-03	307.7	2,383.7	327.6	11.3	0.0	1,541.2	18.2	9.3	0.0	0.0	4598.9
B09-04	313.2	921.2	23.4	0.0	0.0	192.0	20.0	0.9	0.0	0.7	1471.4
B09-05	147.0	778.9	30.9	0.0	0.0	570.2	7.3	58.3	0.0	16.9	1609.5
B09-06	284.1	2,696.9	221.2	72.5	1.5	1,333.5	23.1	330.8	0.0	387.8	5351.4
B09-07	32.2	1,242.5	25.3	0.0	0.0	601.8	5.1	60.1	0.0	6.3	1973.3
B09-08	41.8	2,078.5	99.3	0.1	0.0	1,131.1	6.8	112.0	0.0	160.1	3629.5
B09-09	322.2	1,444.4	78.5	0.0	0.0	1,266.3	19.0	298.9	4.3	5.6	3439.1
B09-10	0.0	530.5	78.0	0.0	0.0	671.9	5.1	222.6	0.0	0.0	1508.1
B09-11	438.7	3,854.6	598.1	30.1	0.0	1,599.2	30.3	166.6	0.0	71.1	6788.7
B09-12	0.0	44.4	31.2	0.0	0.0	45.7	0.0	5.5	0.0	6.0	132.8
B09-13	58.0	1,284.0	232.3	15.7	0.0	1,462.6	7.6	703.5	46.7	698.2	4508.6
B09-14	0.0	79.1	41.9	0.0	0.0	49.6	0.0	2.0	0.0	0.0	172.6
Total	2,304.3	20,243.3	2067.3	131.3	1.5	12,139.3	167.8	2,093.3	51.0	1,389.7	40,588.8

5.5. Accounting for Pollutant Sources

5.5.1. Overview

There were 45 VADEQ permitted fecal coliform point sources in the Abrams Creek and Upper and Lower Opequon Creek watershed. Of the 45 permitted sources, 43 of them were general permits for facilities/residences discharging at or less than 1000 gallons per day (Table 4.2). For the remaining permitted fecal coliform discharges, the Parkins Mills STP (VA0075191) is permitted to discharge 2.0 million gallons per day (MGD) year round; the Opequon Regional Advanced Wastewater Treatment Plant (VA0065552) is permitted to discharge 8.4 MGD from June through November, and 16 MGD the remainder of the year. The fecal coliform concentration in the discharges from these facilities cannot exceed 200 cfu/100mL. These sources were incorporated into the simulations using the loads specified in the permit for allocation scenarios. In addition, two MS4 permits were located in the Abrams Creek watershed, VAR040053 and VAR040032. While the MS4 permits are regulated similarly to point source discharges, water quality discharging from the MS4s is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). Fecal coliform loads modeled from impervious areas within the MS4 areas are included in the wasteload allocation (WLA) component of the TMDL, in compliance with 40 CFR §130.2(h). Fecal coliform loads related to stormwater runoff from areas covered by MS4 permits were modeled with HSPF as contributions from impervious land use categories.

Fecal coliform loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Fecal coliform that is land-applied or deposited on land was treated as nonpoint source loading; all or part of that load may get transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loading was applied to the stream in each sub-watershed as appropriate.

Nonpoint source loading was applied as fecal coliform counts to the pervious fraction of each land use category in a sub-watershed on a monthly basis. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams. Nonpoint source loading was applied as fecal coliform counts to the impervious fraction of each land use category in a sub-watershed at a constant rate. These constant application rates are a function of land use and are discussed in detail in Section 5.5.3. Fecal coliform die-off was simulated during periods when manure is stored, while on the land between runoff generating precipitation events, and while in streams.

5.5.2. Modeling fecal coliform die-off

Fecal coliform die-off was modeled using a first order die-off equation of the form:

$$C_t = C_0 10^{-Kt} \quad [5.1]$$

where:

C_t = concentration or load at time t,
C_0 = starting concentration or load (cfu/ 100ml),
K = decay rate (day^{-1}), and
t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Abrams Creek and Upper Opequon Creek and Lower Opequon Creek watersheds (Table 5.8).

Table 5.8. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day^{-1})	Reference
Dairy manure	Pile (not covered)	0.066	Jones (1971)[a]
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Coles (1973)[a]

[a]Cited in Crane and Moore (1986)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Because the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day^{-1}) was used.

- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day^{-1}) reported for solid dairy manure, a decay rate of 0.05 day^{-1} was used assuming that a majority of manure piles are not covered.

The procedure for calculating fecal coliform counts in waste at the time of land application is included in Appendix D. Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. By multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure), the amount of fecal coliform available for application to land per year is estimated. Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A decay rate of 0.045 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.045 day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.15 day^{-1} (USEPA, 1985) was used.

5.5.3. Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 4. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human and pet populations, and fecal coliform production rates. Fecal coliform in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture. For a given period of storage, the total amount of fecal coliform present in the stored manure was adjusted for die-off on a daily basis. Fecal coliform loadings to each sub-watershed in the Abrams Creek, Upper Opequon Creek, and Lower Opequon Creek watersheds are presented in Appendix F. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland: Where applicable liquid dairy manure and solid manure are applied to cropland as described in Chapter 4. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land-application. Wildlife contributions were also added to the cropland areas. For modeling, monthly fecal coliform loading assigned to cropland was distributed over as many acres within the sub-watershed as were need to utilize the generated manure. Thus, loading rate varied by month and sub-watershed.

2. Pasture: The only deposition of manure or pasture resulted form direct deposition from livestock and wildlife as described in Chapter 4. For modeling, monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.

3. Low Density Residential (LDR) and Farmstead: Fecal coliform loading on the pervious fraction of these land use categories is described in Chapter 4. Low density residential and Farmstead land use loading came from failing septic systems, wildlife and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were combined and assumed to be uniformly applied. Loading to the impervious fraction of this land use category was assumed to be constant at an average $4x10^8$ cfu/ac/day in Abrams Creek and $1x10^7$ cfu/ac/day in the Upper and Lower Opequon Creek watersheds.

4. High-Density Residential (HDR): Fecal coliform loadings on the pervious fraction of this land use were allowed to vary monthly. Loading to the impervious fraction of this land use category was assumed to be constant at an average $3.0x10^9$ cfu/ac/day in Abrams Creek and $1x10^7$ cfu/ac/day in the Upper and Lower Opequon Creek watersheds. Source categories contributing to this watershed include pets and wildlife.

5. Forest: Wildlife not defecating in streams or on cropland and pastures provided fecal coliform loading to the forested land use. Fecal coliform from wildlife was

applied uniformly over the forest areas, except for the percentage considered as direct load to forested streams.

6. Urban: This land use category was comprised chiefly of the commercial/industrial areas. Fecal coliform loadings on the pervious fraction of this land use were allowed to vary monthly. Loading to the impervious fraction of this land use category was assumed to be constant at an average 6.0×10^8 cfu/ac/day in the Abrams Creek watershed and 1×10^7 cfu/ac/day in the Upper and Lower Opequon Creek watersheds. Source categories contributing to this watershed included pets and wildlife.

5.5.4. Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams and wildlife in streams. Also, contributions of fecal coliform from interflow and groundwater were modeled as having a constant concentration of 25 cfu/100mL. Loads from direct nonpoint sources in each watershed are described in detail in Chapter 4.

5.6. Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for time periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the hydrology component and the calibration results of the water quality component are presented.

5.6.1. Abrams Creek

5.6.1.a. Hydrology

The hydrologic calibration period for Abrams Creek was 1986 to 1988, inclusive. The Abrams sewage treatment plant (VA0031780) was active during the entire period, and its flow was represented in HSPF. The hydrologic validation period was from 1980 to 1985. The Abrams STP (sewage treatment plant) (VA0031780) was active during the latter part of this period and was so represented in HSPF. Observed daily flow data for

Abrams Creek were available from the USGS Gage 01616000 near the city of Winchester, VA, at a location close to the outlet of the watershed. The daily average flow data were used in the hydrologic calibration/validation. The output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range.

The HSPEXP decision support system developed by USGS was used to calibrate the hydrologic portion of HSPF for Abrams Creek. The default HSPEXP criteria for evaluating the accuracy of the flow simulation were used in the calibration for Abrams Creek. These criteria are listed in Table 5.9. After calibration, all criteria listed in Table 5.9 were met.

Table 5.9. Default criteria for HSPEXP.

Variable	Percent Error
Total Volume	±10
50 % Lowest Flows	±10
10 % Highest Flows	±15
Storm Peaks	±15
Seasonal Volume Error	±10
Summer Storm Volume Error	±15

The simulated flow for both the calibration and validation matched the observed flow well, as shown in Figures 5.4 and 5.5. The agreement with observed flows is further illustrated in Figures 5.6 and 5.7 for a representative year and Figures 5.8 and 5.9 for a representative storm. See Section 5.3.1 for a discussion of the climatological inputs.

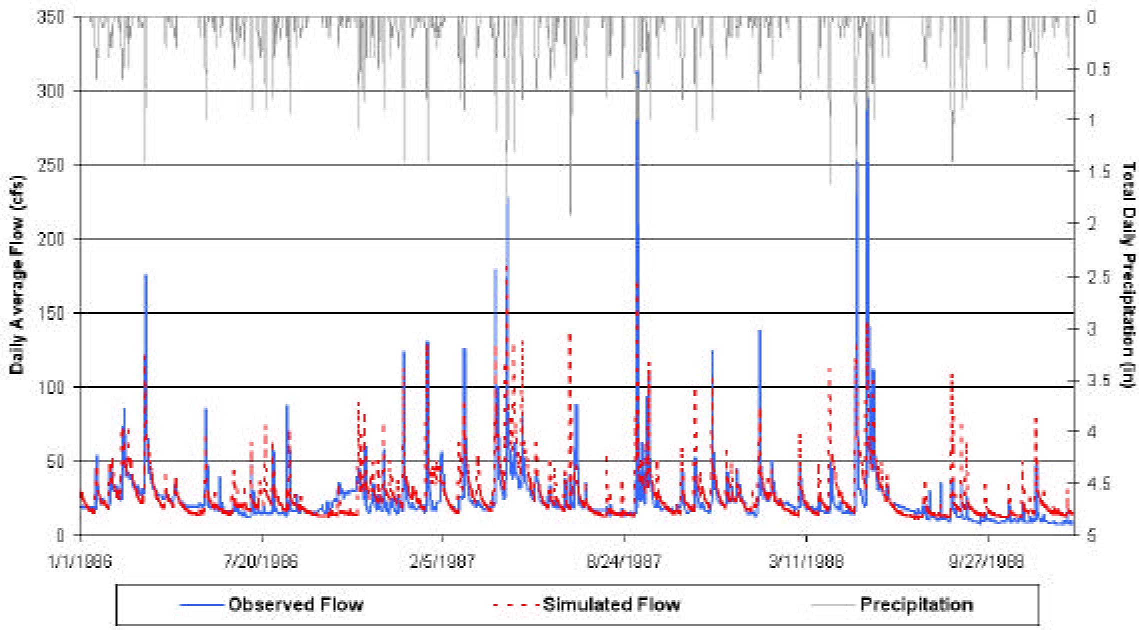

Figure 5.4. Observed and simulated flows, and precipitation for the calibration period: Abrams Creek.

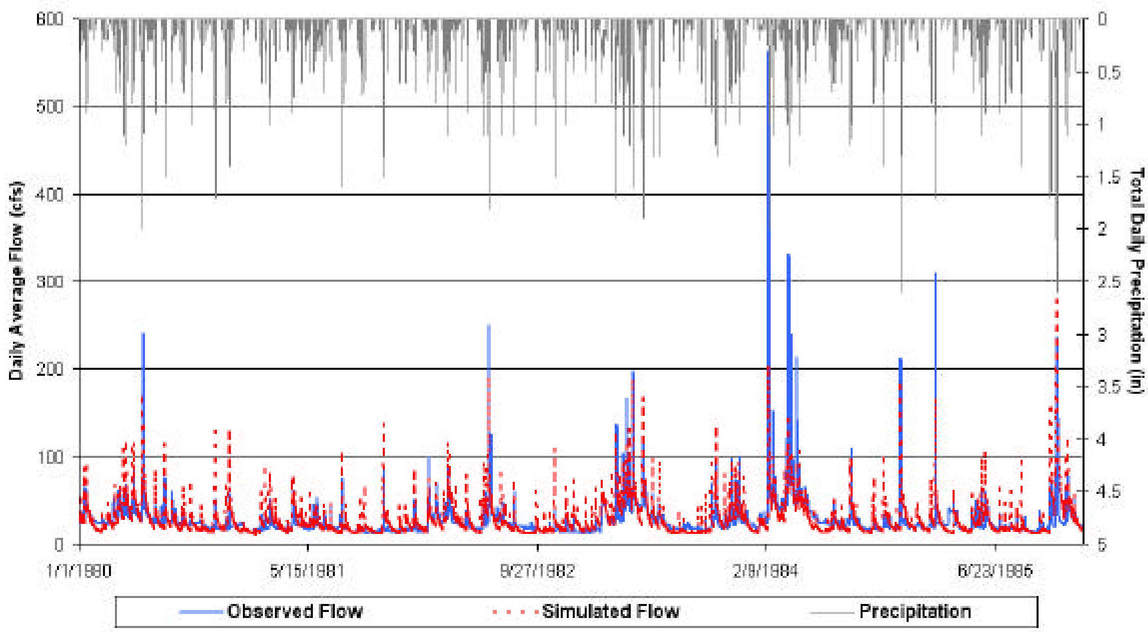

Figure 5.5. Observed and simulated flows, and precipitation during the validation period: Abrams Creek.

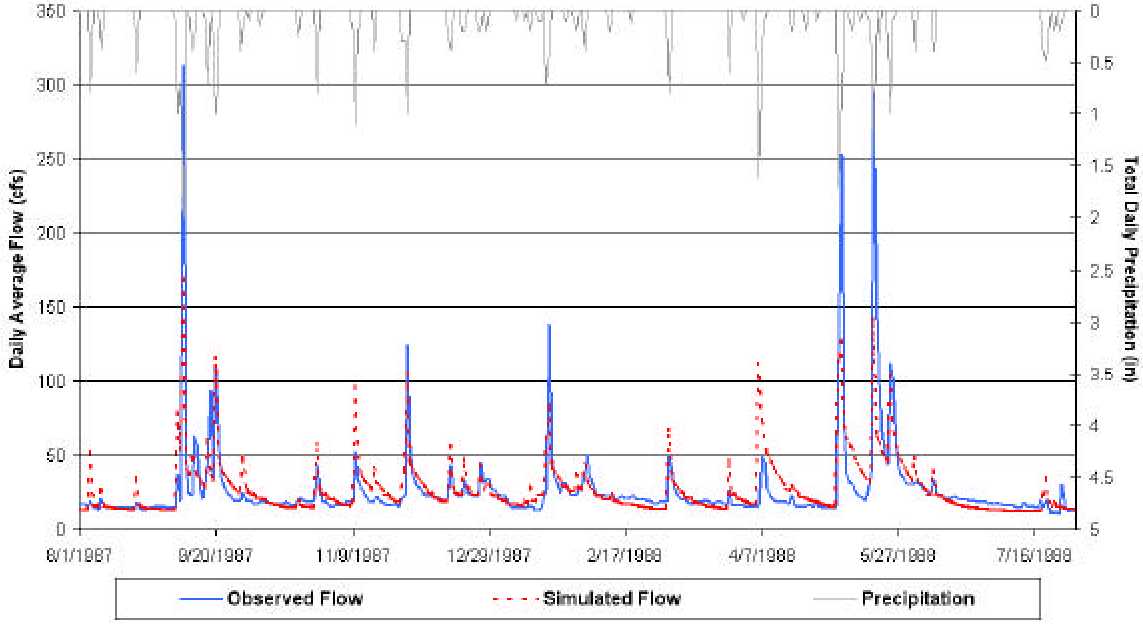

Figure 5.6. Observed and simulated flows, and precipitation for a representative year in the calibration period: Abrams Creek.

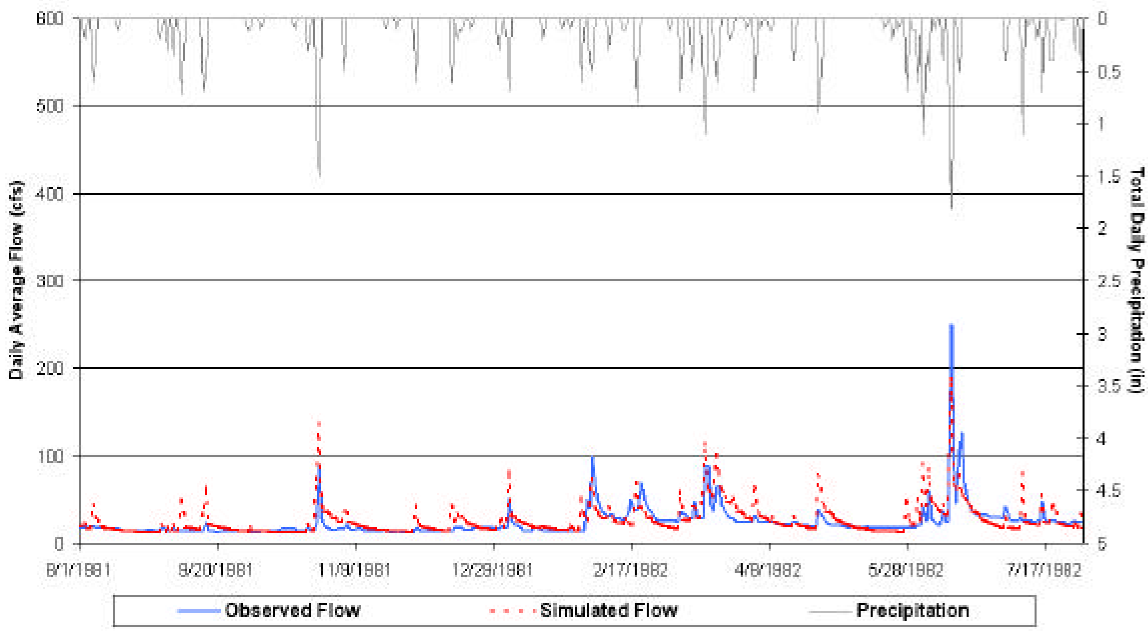

Figure 5.7. Observed and simulated flows, and precipitation during a representative year in the validation period: Abrams Creek.

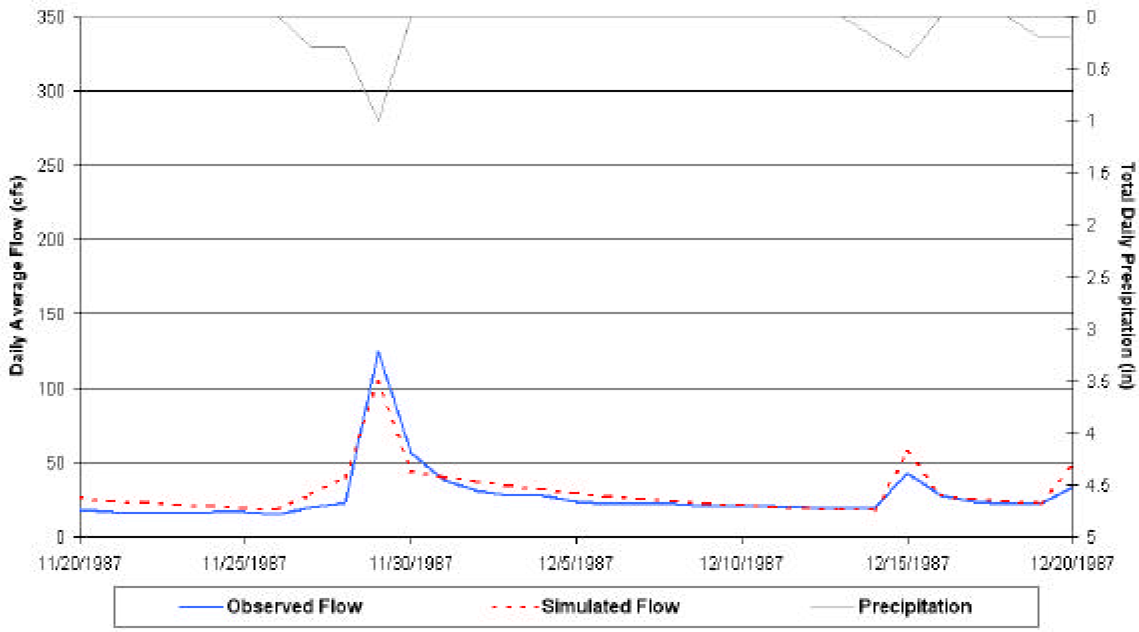

Figure 5.8. Observed and simulated flows, and precipitation for a representative Storm in the calibration period: Abrams Creek.

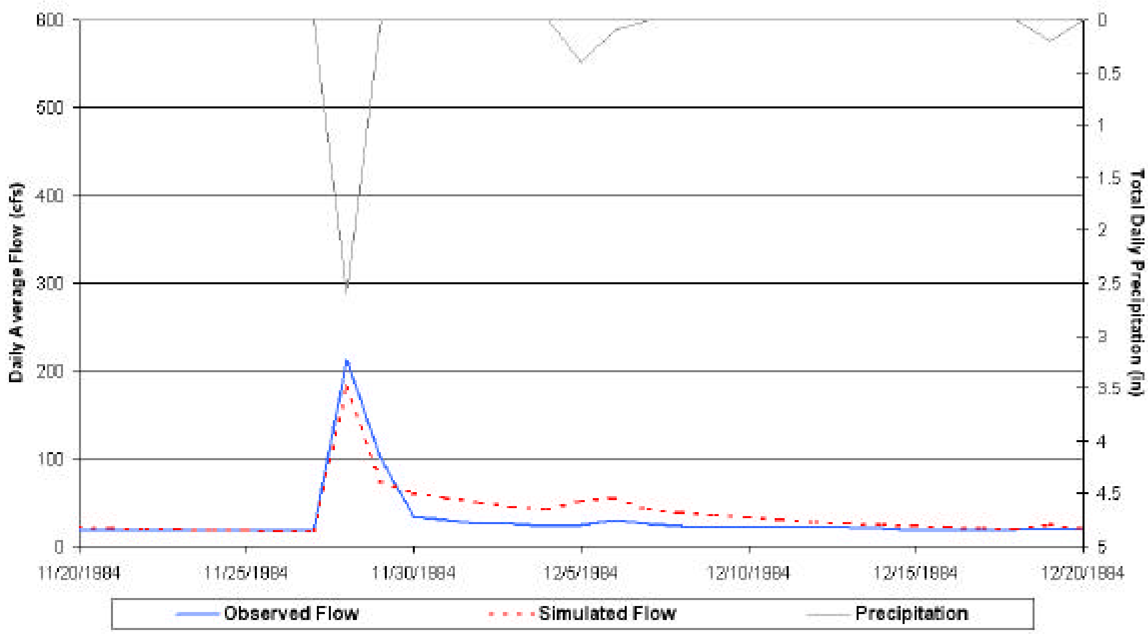

Figure 5.9. Observed and simulated flows, and precipitation for a representative Storm in the validation period: Abrams Creek.

The agreement of the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figures 5.10 and 5.11).

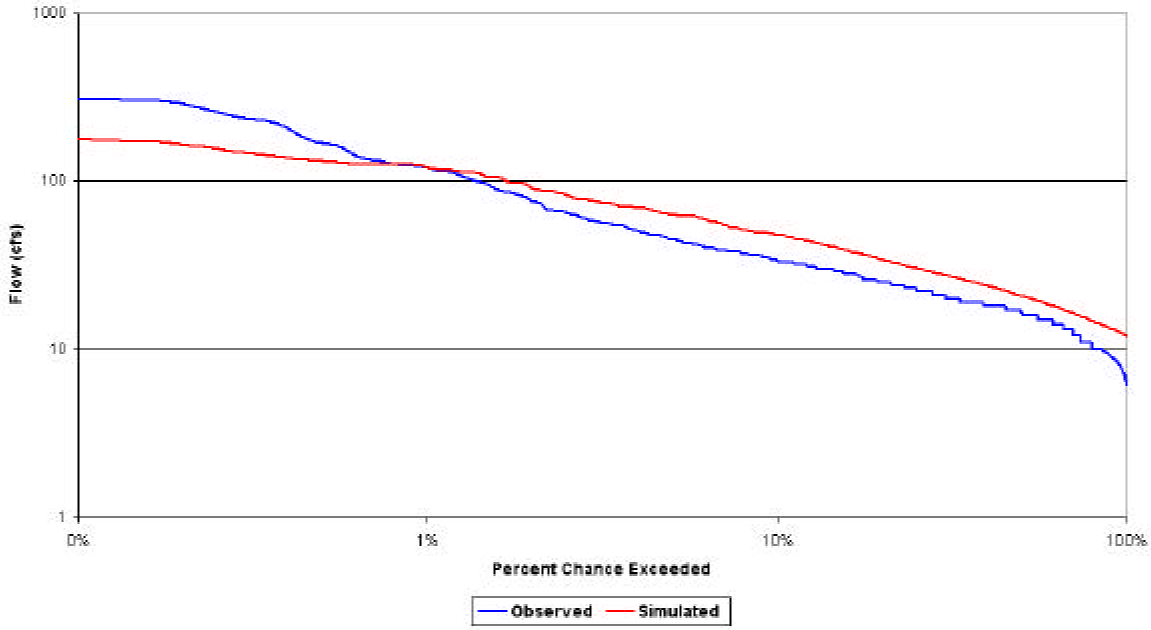

Figure 5.10.Cumulative frequency curves for the calibration period: Abrams Creek.

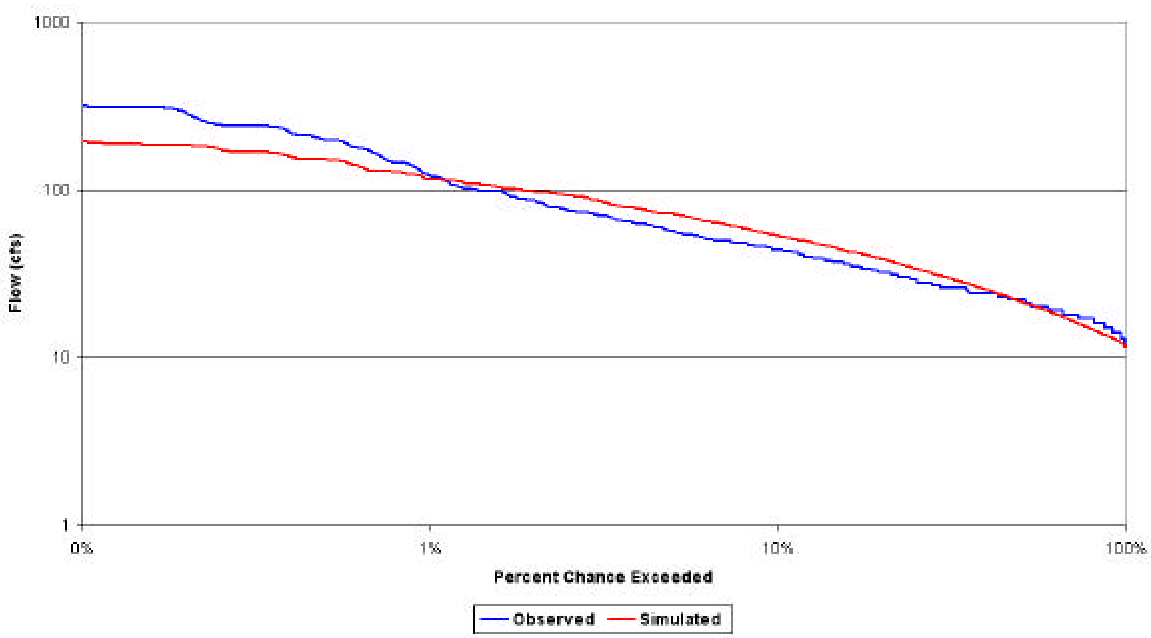

Figure 5.11. Cumulative frequency curves for the validation period: Abrams Creek.

The expert system HSPEXP was used to assist with calibrating and validating the Abrams Creek hydrologic model. Selected diagnostic output from the program is listed in Tables 5.10 and 5.11. The total winter runoff and total summer runoff errors are considered in the HSPEXP term 'seasonal volume error' (Table 5.9). The errors for seasonal volume error were 0.7% for the calibration period and 9.7% for the validation period, both are within the required range of ± 10%.

Table 5.10. Summary statistics for the calibration period: Abrams Creek.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	62.800	57.150	+9	±10%
Average Annual Total Runoff	20.933	19.050	+9	±10%
Total of Highest 10% of flows	16.960	16.617	+2	±15%
Total of Lowest 50% of flows	18.330	17.001	+7	±15%
Total Winter Runoff	15.870	14.147	+11	na
Total Summer Runoff	12.390	10.976	+11	na
Coefficient of Determination, r^2	0.626			

na = not applicable; these are not criteria directly considered by HSPEXP

Table 5.11. Summary statistics for the validation period: Abrams Creek.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	135.100	128.466	+5	±10%
Average Annual Total Runoff	22.517	21.411	+5	±10%
Total of Highest 10% of flows	37.640	35.456	+6	±15%
Total of Lowest 50% of flows	37.100	39.973	-8	±15%
Total Winter Runoff	32.150	30.558	+5	na
Total Summer Runoff	28.120	29.455	-5	na
Coefficient of Determination, r^2	0.523			

na = not applicable; these were not criteria directly considered by HSPEXP

Flow partitioning for Abrams Creek hydrologic model calibration and validation is shown in Table 5.12. When the observed flow data was evaluated using HYSEP, the baseflow indices for the calibration and validation periods were 0.76 and 0.83 respectively. We feel the simulated baseflow indices shown in Table 5.12 match these observed values well.

Table 5.12. Flow partitioning for the calibration and validation periods: Abrams Creek.

Average Annual Flow	Calibration	Validation
Total Annual Runoff (in)	482.3	561.9
Surface Runoff (in)	121.8 (25%)	136.8 (24%)
Interflow (in)	7.4 (2%)	5.8 (1%)
Baseflow (in)	353.0 (73%)	419.4 (75%)
Baseflow Index	0.73	0.75

A list of final calibration parameters for both the hydrology and water quality simulations can be found at the end of the next section (Table 5.15).

5.6.1.b. Fecal coliform calibration

The water quality calibration was performed at an hourly time step using the HSPF model. The water quality calibration period was June 1, 1992 through June 30, 1997. There were no point sources of bacteria in the Abrams Creek watershed. Fecal coliform (FC) observations from the VADEQ ambient water quality monitoring station 1AABR000.78 were used to calibrate the water quality component of HSPF for Abrams Creek. Output from the HSPF model was generated as an hourly time series and daily average timeseries of fecal coliform concentration. *E. coli* concentrations were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad [5.2]$$

The geometric mean was calculated on a monthly basis. The final calibration parameters are shown in Table 5.15.

The BST results for Abrams Creek are shown in Table 5.13. Table 5.14 contains the simulated percent contributions from the major source categories to the in-stream load during the calibration period.

Table 5.13. Bacterial source tracking results at the Abrams Creek station.

		ARA - Enterococci			
Location	**DATE**	**Wildlife**	**Human**	**Livestock**	**Cats/Dogs**
1AABR000.78	6/12/2002	58%	0%	0%	42%
1AABR000.78	7/25/2002	39%	0%	15%	46%
1AABR000.78	8/23/2002	52%	0%	19%	29%

1AABR000.78	9/27/2002	27%	0%	2%	71%
1AABR000.78	10/30/2002	4%	2%	0%	94%
1AABR000.78	11/22/2002	23%	21%	8%	48%

Table 5.14. Simulated percent contributions from major source categories during the calibration period: Abrams Creek.

Scenario	Livestock DD	Livestock Land	Wildlife DD	Wildlife Land	Septic Systems	Pets	Impervious	Interflow and Groundwater
Total period	0.9%	0.6%	2.9%	0.4%	0.4%	0.7%	92.8%	1.3%
Periods of no rainfall	22.5%	0%	63.9%	0%	0%	0%	0%	13.6%

Because BST samples are collected periodically, the conditions under which they are collected differ over time. As a result, when comparing Table 5.13 and Table 5.14, it is appropriate to compare the BST data shown in Table 5.13 to both the “Total period” and “Periods of no rainfall” simulated percent contribution values in Table 5.14. Examining Table 5.13 and Table 5.14 one sees that the simulated wildlife contributions agree well with the wildlife BST data. The low percent contributions from septic systems shown in Table 5.14 corresponded well to the human contribution in the BST data, which is routinely 0%. And, the simulated contributions from livestock closely match the observed BST data. Although the pet contribution appears low in the simulated data, the simulated impervious contributions, which are primarily from pets, corresponds well to the observed cats/dogs BST data.

In addition to correlating well with the BST results, the simulated fecal coliform concentrations agree well with the observed fecal coliform concentrations. Figure 5.12 shows the daily average simulated fecal coliform concentrations and the observed data. The overall maximum daily simulated concentration for the calibration period was 29,200 cfu/100 mL; the maximum concentration for the observed data during that period was at the capped value of 8,000 cfu/100 mL.

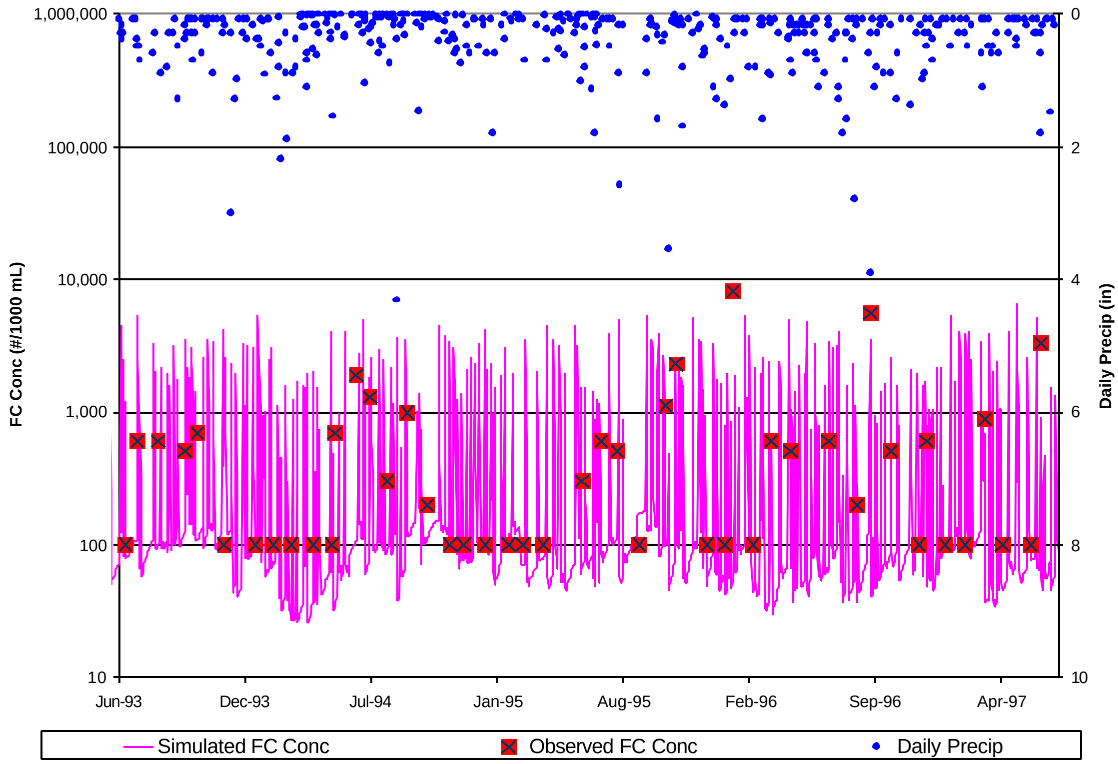

Figure 5.12. Observed and Simulated Fecal Coliform Concentrations for the Water Quality Calibration Period: Abrams Creek.

The geometric mean for the simulated data for the calibration period is 145 cfu/100 mL; the geometric mean for the observed data for the same period is 289 cfu/100 mL. However, there is a lower cap on the observed data at 100 cfu/100 mL. Over fifty percent of the observed samples were at the lower cap value of 100 cfu/100 mL, which may cause the observed geometric mean to be artifically high.

The violation rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL is 43% for the observed data and 19% for the simulated data. The observed data is very 'flashy' i.e., it is either in violation of the standard (43%) or below the detection limit (50%), with very few samples (7%) in between. There were only 58 observed samples, whereas the simulation created 1856 daily average fecal coliform values. The observed samples are a very small snapshot of the entire period. If one considers only the conditions surrounding the collection of the observed values, the instantaneous violation rates are much more similar. The average of the simulated values for the 5-day window surrounding the collection of observed samples (i.e., 2 days before sampling, the day of sampling, and 2 days after sampling) were considered. The violation rate for these 5-day averages for the observed data collection times was 43%.

This shows that the conditions surrounding the sample collection days caused the fecal coliform rates to be elevated as compared to the entire period of simulation. Therefore, we believe that the simulation produces and accurate picture of the existing conditions in the watershed. Because the observed samples were collected on a monthly basis, a comparison of violations of the geometric mean criterion cannot be conducted.

The final parameters used in the calibration and validation simulations are listed in Table 5.15.

Table 5.15.Input parameters used in HSPF simulation: Abrams Creek.

Parameter	Definition	Units	RANGE OF VALUES				START	FINAL CALIB.	FUNCTION OF...
			TYPICAL		POSSIBLE				
			MIN	MAX	MIN	MAX			
PERLND									
PWAT-PARM2									
FOREST	Fraction forest cover	none	0.00	0.5	0	0.95	0.0, 1.0	1.0 forest, 0.0 other	Forest cover
LZSN	Lower zone nominal soil moisture storage	inches	3	8	2	15	14.1	5-15	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.16	1.00 Forest, 0.75 other[1]	Soil and cover conditions
LSUR	Length of overland flow	feet	200	500	100	700	300	238-246	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.035	0.02-0.04[1]	Topography
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.98	0.88	Calibrate
PWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.2	0	0.5	0.1	0.1	Geology
BASETP	Fraction of remaining ET from baseflow	none	0	0.05	0	0.2	0.02	0.0	Riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0	0.05	0	0.2	0	0	Marsh/wetlands ET
PWAT-PARM4									
CEPSC	Interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	0.25 cropland, 0.05 other	Vegetation
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1	0.05	2	1.128	1.8	Soil properties
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	0.15-0.45[1]	Land use, surface condition
INTFW	Interflow/surface runoff partition parameter	none	1	3	1	10	0.75	5.0	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.5	0.99	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	monthly	0.3	Vegetation
QUAL-INPUT									
ACQOP[1]	Rate of accumulation of constituent	#/day						monthly	Land use
SQOLIM[1]	Maximum accumulation of constituent	#						monthly	Land use
WSQOP	Wash-off rate	in/hr						2.5	Land use
IOQC	Constituent conc. in interflow	#/ft3						8496	Land use
AOQC	Constituent conc. in	#/ft3						5664	Land use

	active groundwater								

Table 5.15.Input parameters used in HSPF simulation: Abrams Creek.

			RANGE OF VALUES				START	FINAL CALIB.	FUNCTION OF…
			TYPICAL		POSSIBLE				
Parameter	**Definition**	**Units**	**MIN**	**MAX**	**MIN**	**MAX**			
IMPLND									
IWAT-PARM2									
LSUR	Length of overland flow	feet	200	500	100	700	300	250	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.035	0.01	Topography
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	0.20	Land use, surface condition
RETSC	Retention/interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	0.150	Land use, surface condition
IWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
IQUAL									
ACQOP	Rate of accumulation of constituent	#/day						4.0×10^{8}-3.0×10^{9}	Land use
SQOLIM	Maximum accumulation of constituent	#						4.0×10^{9}-3.0×10^{10}	Land use
WSQOP	Wash-off rate	in/hr						0.5	Land use
RCHRES									
HYDR-PARM2									
KS	Weighting factor for hydraulic routing							0.3	
GQUAL									
FSTDEC	First order decay rate of the constituent	1/day						1.15	
THFST	Temperature correction coeff. for FSTDEC							1.05	

[1]Varies with land use

5.6.2. Upper Opequon Creek

5.6.2.a. Hydrology

The hydrologic calibration period was October 1987 through September 1992 for Upper Opequon Creek. The hydrologic validation period was from October 1992 through September 1997. Observed daily flow data for Upper Opequon Creek were available from the USGS Gage 01615000 near the city of Berryville, VA, at a location close to the outlet of the watershed. The permitted flow rates for the VPDES dischargers in the watershed (Table 4.1) and the general permit dischargers (Table 4.2) were used in the hydrologic calibration/validation. These discharges continue to operate and will be included in simulation of future conditions at their permitted discharge rates. The output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range.

The HSPEXP decision support system developed by USGS was used to calibrate the hydrologic portion of HSPF for Upper Opequon Creek. The default HSPEXP criteria for evaluating the accuracy of the flow simulation were used in the calibration for Upper Opequon Creek. These criteria are listed in Table 5.9. After calibration, all criteria listed in Table 5.9 were met.

The simulated flow for both the calibration and validation matched the observed flow well, as shown in Figures 5.13 and 5.14. The agreement with observed flows is further illustrated in Figures 5.15 and 5.16 for a representative year and Figures 5.17 and 5.18 for a representative storm. See Section 5.3.1 for a description of the climatological data.

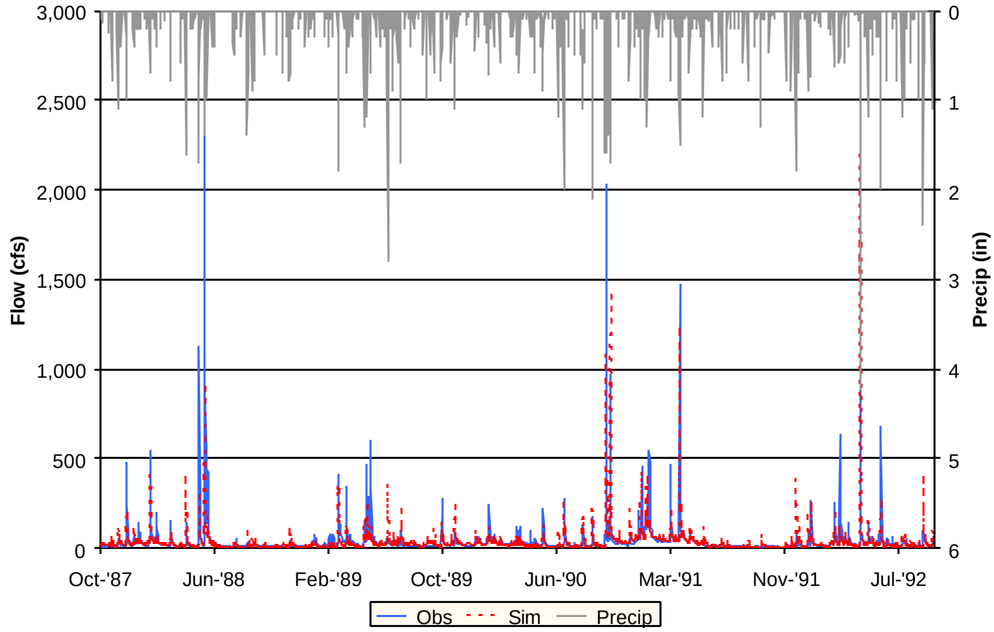

Figure 5.13. Observed and simulated flows, and precipitation for the calibration period: Upper Opequon Creek.

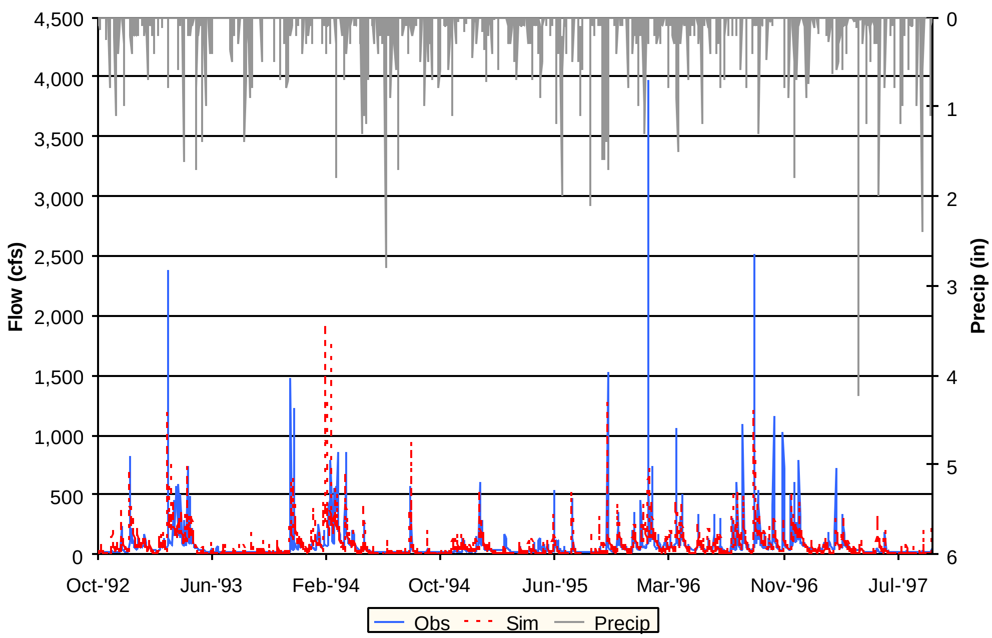

Figure 5.14. Observed and simulated flows, and precipitation during the validation period: Upper Opequon Creek.

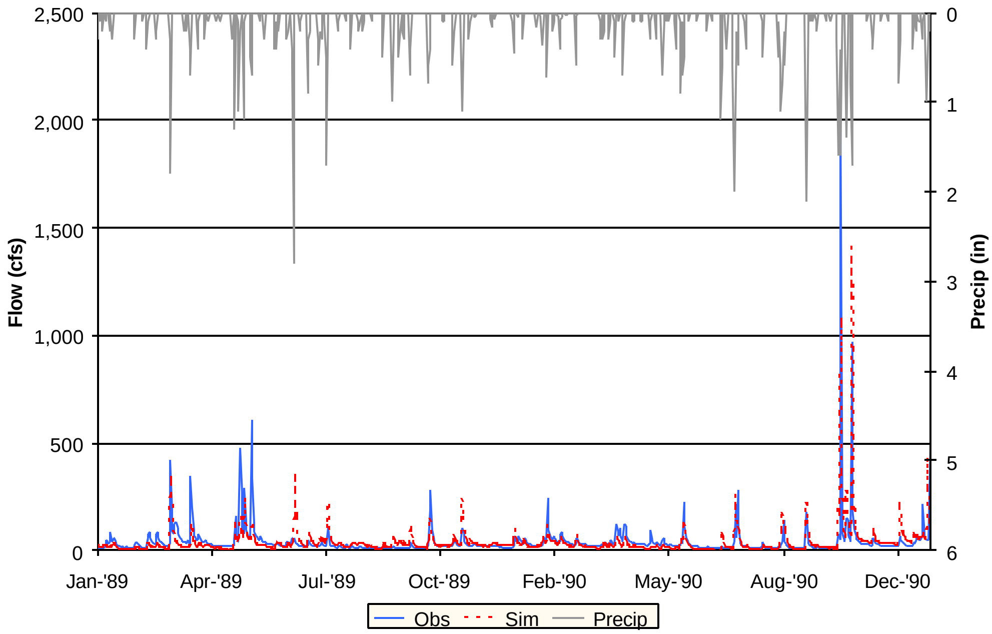

Figure 5.15. Observed and simulated flows, and precipitation for a representative year in the calibration period: Upper Opequon Creek.

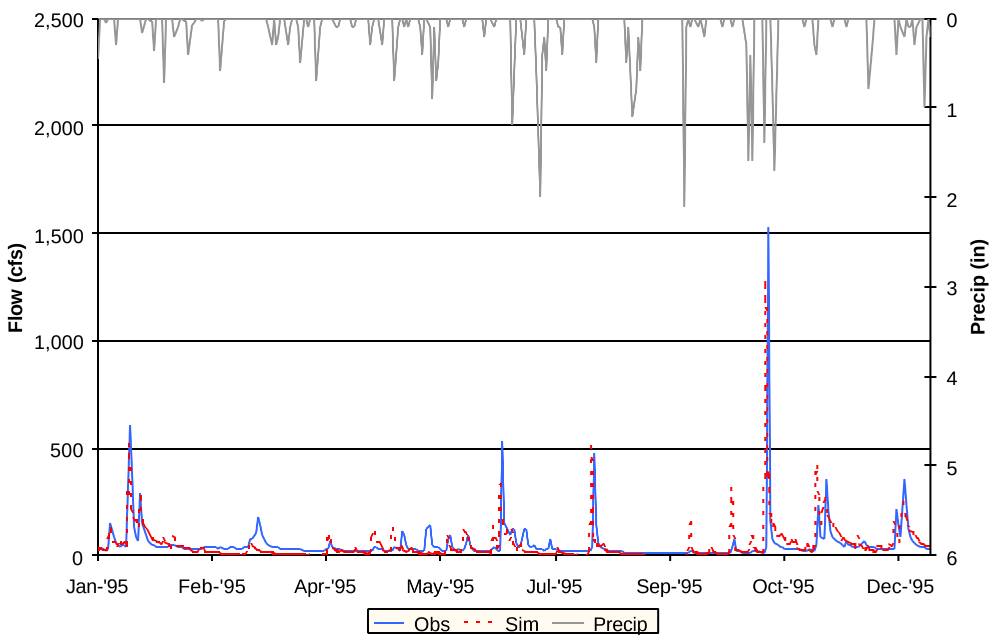

Figure 5.16. Observed and simulated flows, and precipitation during a representative year in the validation period: Upper Opequon Creek.

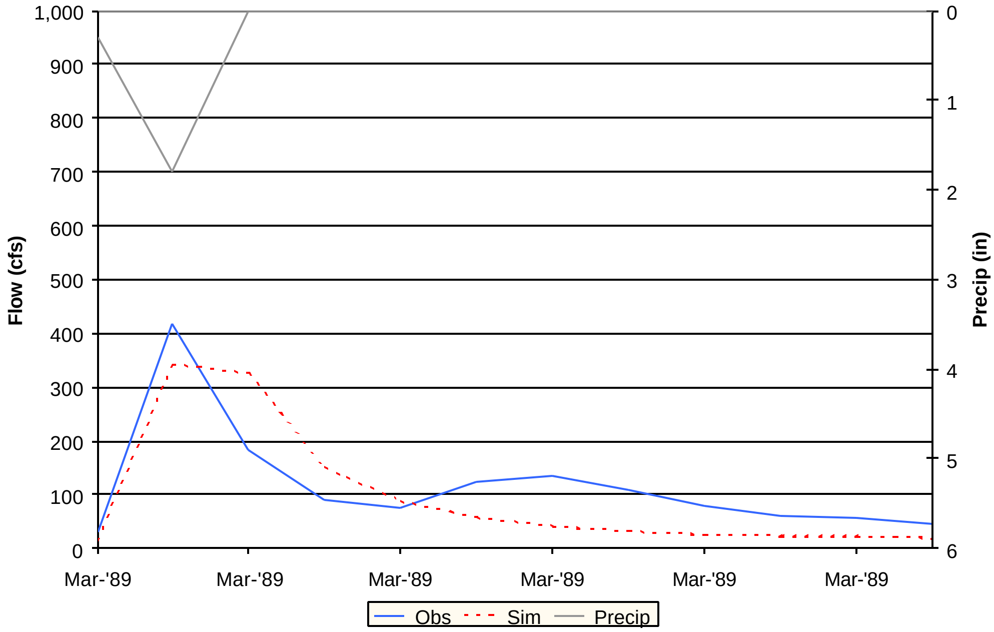

Figure 5.17. Observed and simulated flows, and precipitation for a representative Storm in the calibration period: Upper Opequon Creek.

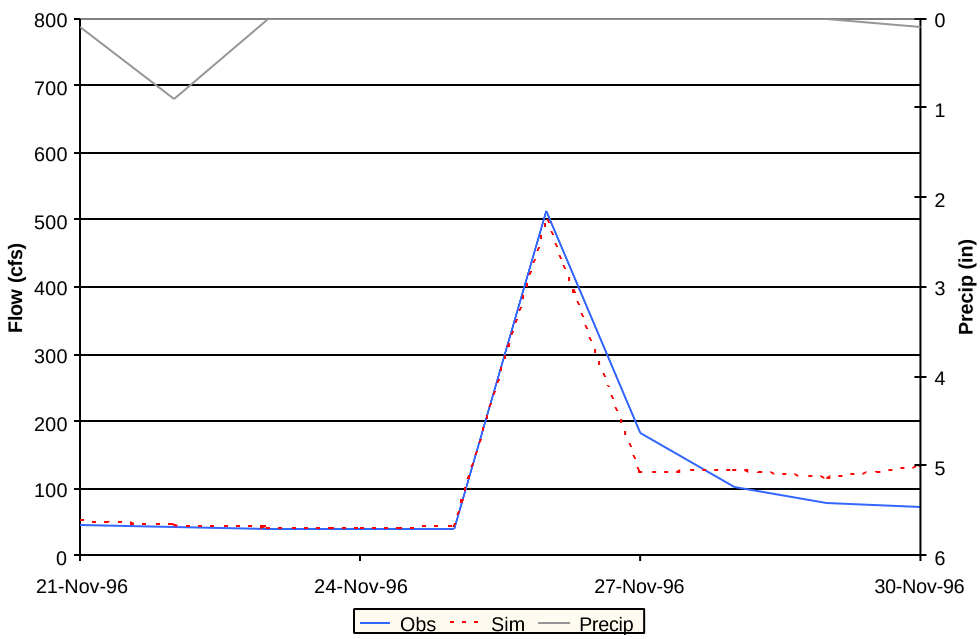

Figure 5.18. Observed and simulated flows, and precipitation for a representative Storm in the validation period: Upper Opequon Creek.

The agreement of the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figures 5.19 and 5.20).

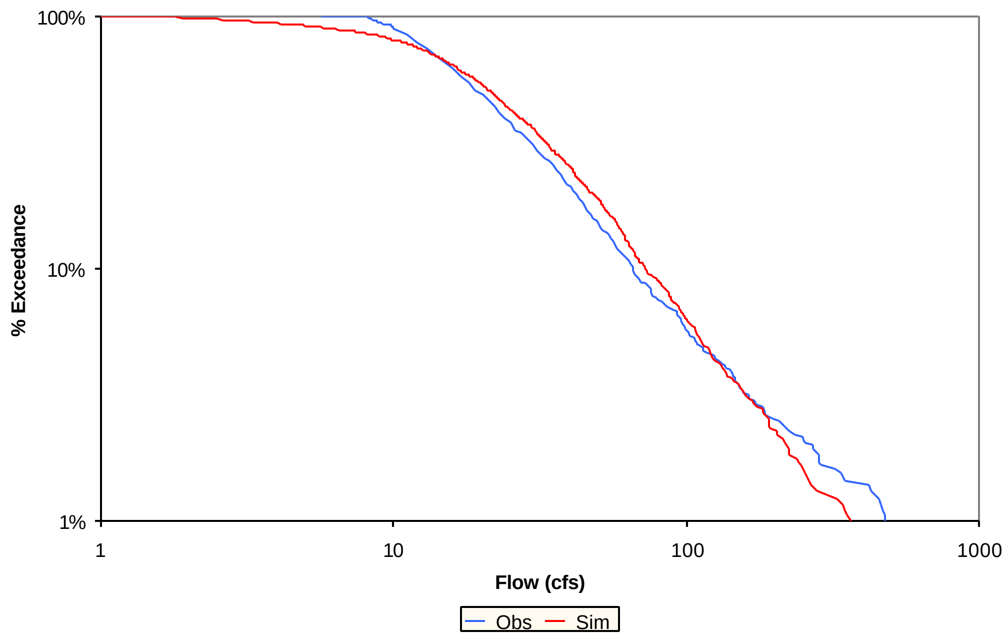

Figure 5.19. Cumulative frequency curves for the calibration period: Upper Opequon Creek.

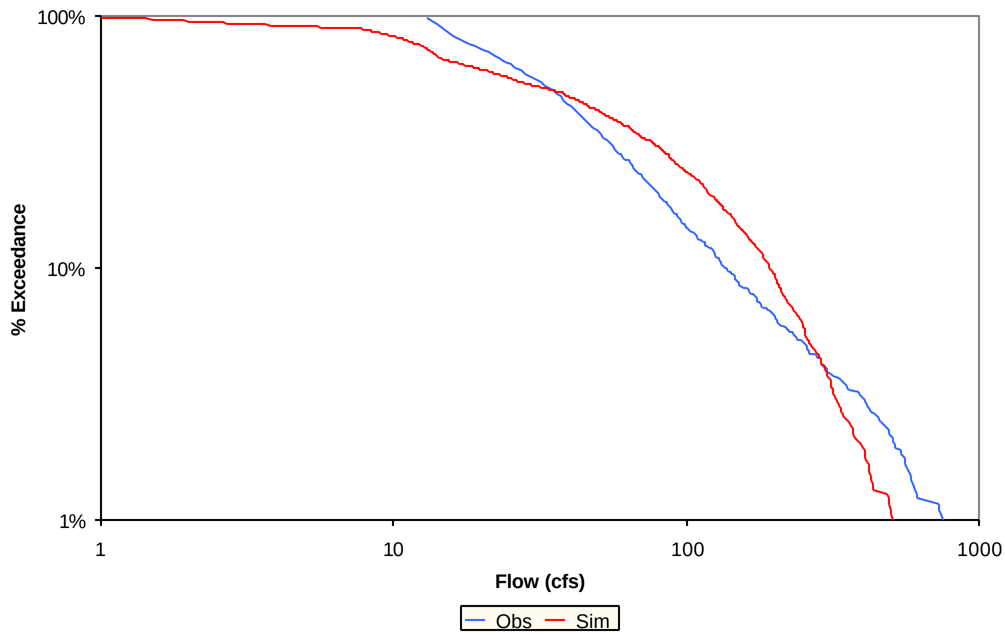

Figure 5.20. Cumulative frequency curves for the validation period: Upper Opequon Creek.

The expert system HSPEXP was used to assist with calibrating and validating the Upper Opequon Creek hydrologic model. Selected diagnostic output from the program is listed in Tables 5.16 and 5.17). The total winter runoff and total summer runoff errors are considered in the HSPEXP term 'seasonal volume error' (see Table 5.9). The errors for seasonal volume error were 1.5% for the calibration period and 3.8% for the validation period, both are within the required range of ± 10%.

Table 5.16. Summary statistics for the calibration period: Upper Opequon Creek.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	49.850	50.310	-0.9	10%
Average Annual Total Runoff	9.70	10.062	-3.6	10%
Total of Highest 10% of flows	23.760	26.202	-9.3	15%
Total of Lowest 50% of flows	7.190	7.937	-9.4	15%
Total Winter Runoff	13.630	12.790	+9.6	Na
Total Summer Runoff	0.500	0.522	-4.2	Na
Coefficient of Determination, r^2	0.611			

na = not applicable; these are not criteria directly considered by HSPEXP

Table 5.17. Summary statistics for the validation period: Upper Opequon Creek.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	90.620	88.634	+2.2	10%
Average Annual Total Runoff	18.120	17.785	+1.9	10%
Total of Highest 10% of flows	44.080	44.665	-3.5	15%
Total of Lowest 50% of flows	12.160	12.569	-3.3	15%
Total Winter Runoff	30.700	28.826	-6.5	Na
Total Summer Runoff	12.930	12.194	-6.0	Na
Coefficient of Determination, r^2	0.375			

na = not applicable; these were not criteria directly considered by HSPEXP

Flow partitioning for Upper Opequon Creek hydrologic model calibration and validation is shown in Table 5.18. When the observed flow data was evaluated using HYSEP, the baseflow indices for the calibration and validation periods were 0.56 and 0.48 respectively. We feel the simulated baseflow indices shown in Table 5.18 match these observed values well.

Table 5.18. Flow partitioning for the calibration and validation periods: Upper Opequon Creek.

Average Annual Flow	Calibration	Validation
Total Annual Runoff (in)	9.97	18.12
Surface Runoff (in)	3.83 (39%)	7.58 (42%)
Interflow (in)	0.42 (%)	1.17 (6%)
Baseflow (in)	5.72 (57%)	9.37 (52%)
Baseflow Index	0.57	0.52

A list of final calibration parameters for both the hydrology and water quality simulations can be found at the end of the next section (Table 5.21).

5.6.2.b. Fecal Coliform

The water quality calibration for Upper Opequon Creek was performed at an hourly time step using the HSPF model. The water quality calibration period was September 1, 1992 through September 30, 1997. There were 6 VPDES permitted point sources, and 17 general permit point sources of bacteria in the Upper Opequon Creek watershed during the calibration period. Fecal coliform (FC) observations from the VADEQ ambient water quality monitoring station 1AOPE036.13 were used to calibrate the water quality component of HSPF for Upper Opequon Creek. Output from the HSPF model was generated as an hourly time series and daily average time series of fecal coliform concentration. *E. coli* concentrations were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad (5.1)$$

The geometric mean was calculated on a monthly basis. The final calibration parameters are shown in Table 5.21.

The BST results for Upper Opequon Creek are shown in Table 5.19. Table 5.20 contains the simulated percent contributions from the major source categories to the in-stream load during the calibration period.

Table 5.19. Bacterial source tracking results at the Upper Opequon Creek station.

		ARA - Enterococci			
Location	**DATE**	**Wildlife**	**Human**	**Livestock**	**Cats/Dogs**
1AOPE036.13	3/23/2003	20.8%	4.2%	37.5%	37.5%
1AOPE036.13	5/21/2003	25.0%	20.8%	20.8%	33.4%
1AOPE036.13	6/11/2003	4.2%	45.8%	50.0%	0.0%

Table 5.20. Simulated percent contributions from major source categories during the calibration period: Upper Opequon Creek.

Scenario	Livestock DD	Livestock Land	Wildlife DD	Wildlife Land	Septic Systems	Pets	Impervious	Interflow and Groundwater
Total period	33.0%	35.6%	4.8%	2.7%	8.3%	10.8%	0.1%	1.3%

Examining Table 5.19 and Table 5.20 one sees that the simulated wildlife direct deposit and land surface contributions are a bit lower than most of the wildlife BST data.

The simulated livestock direct deposit and land surface contributions are a little higher than the observed BST data, but are in a reasonable range. Simulated human contributions (from septic systems) fall within the observed range. Simulated pet contributions are slightly underrepresented as compared to the BST results, but still fall within the observed range. Because of the uncertainty associated with both the BST results and the modeling process, overall the comparison is considered to reflect an adequate simulation of existing conditions.

The simulated fecal coliform concentrations agree well with the observed fecal coliform concentrations. Figure 5.21 shows the daily average simulated fecal coliform concentrations and the observed data. The overall maximum simulated concentration for the calibration period was 3,210 cfu/100 mL; the maximum concentration for the observed data during that period was 3,500 cfu/100 mL. While calibrating Upper Opequon, the simulation produced extremely low stages (<0.1 ft) that resulted in extremely high fecal coliform concentrations that are not in the observed record. Some simulated concentrations were in excess of $1.1x10^6$. The simulation process and model capabilities are limited at very low stages. At stages greater than 0.1 ft, the model performs well. To compensate for the concentrations that corresponded to extremely low stages, a filtering technique was employed. That technique (see Appendix I for a more detailed explanation) caps the fecal coliform concentration at stages less than or equal to 0.1 ft at 16,000 cfu/100mL, which is the current VADEQ cap for fecal coliform MPN analysis.

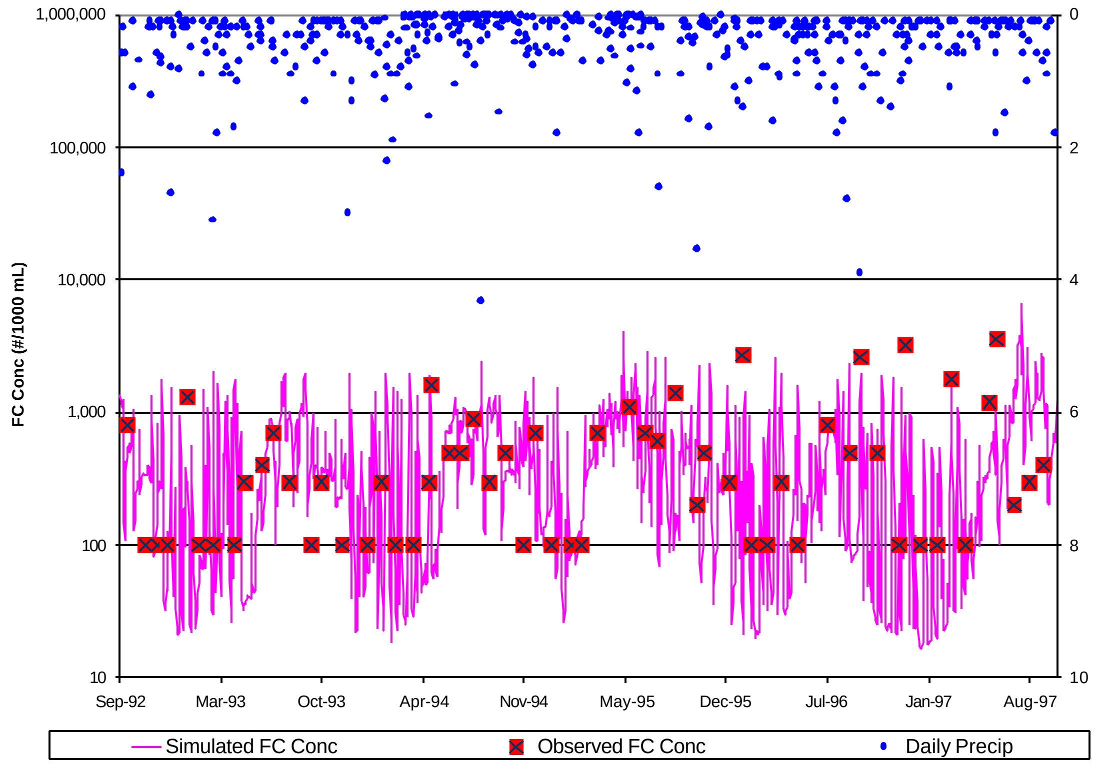

Figure 5.21. Observed and Simulated Fecal Coliform Concentrations for the Water Quality Calibration Period: Upper Opequon Creek.

The geometric mean for the simulated data for the calibration period is 299 cfu/100 mL; the geometric mean for the observed data for the same period is 322 cfu/100 mL. The violation rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL is 44% for the observed data and 49% for the simulated data. Because the observed samples were collected on a monthly basis, a comparison of violations of the geometric mean criterion cannot be conducted.

The final parameters used in the calibration and validation simulations are listed in Table 5.21.

Table 5.21. Input parameters used in HSPF simulations for Upper Opequon Creek.

Parameter	Definition	Units	RANGE OF VALUES TYPICAL MIN	TYPICAL MAX	POSSIBLE MIN	POSSIBLE MAX	START	FINAL CALIB.	FUNCTION OF…
PERLND									
PWAT-PARM2									
FOREST	Fraction forest cover	none	0.00	0.5	0	0.95	0.0, 1.0	1.0 forest, 0.0 other	Forest cover
LZSN	Lower zone nominal soil moisture storage	inches	3	8	2	15	14.1	3.5-8	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.16	0.02-0.15	Soil and cover conditions
LSUR	Length of overland flow	feet	200	500	100	700	300	238-246	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.035	0.02-0.04[1]	Topography
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	0.0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.98	0.99	Calibrate
PWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.2	0	0.5	0.1	0.0	Geology
BASETP	Fraction of remaining ET from baseflow	none	0	0.05	0	0.2	0.02	0.0	Riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0	0.05	0	0.2	0	0.0	Marsh/wetlands ET
PWAT-PARM4									
CEPSC	Interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	0.05-0.25	Vegetation
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1	0.05	2	1.128	1.8	Soil properties
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	0.15-0.45[1]	Land use, surface condition
INTFW	Interflow/surface runoff partition parameter	none	1	3	1	10	0.75	0.75 forest, 0.5 other	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.5	0.90	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	monthly	0.3	Vegetation
QUAL-INPUT									
ACQOP[1]	Rate of accumulation of constituent	#/day						Monthly	Land use
SQOLIM[1]	Maximum accumulation of constituent	#						Monthly	Land use
WSQOP	Wash-off rate	in/hr						2.5	Land use
IOQC	Constituent conc. in interflow	#/ft3						8496	Land use
AOQC	Constituent conc. in active groundwater	#/ft3						5664	Land use

[1]Varies with land use

Table 5.21. Input parameters used in HSPF simulations for Upper Opequon Creek. (Continued)

Parameter	Definition	Units	RANGE OF VALUES TYPICAL MIN	TYPICAL MAX	POSSIBLE MIN	POSSIBLE MAX	START	FINAL CALIB.	FUNCTION OF...
IMPLND									
IWAT-PARM2									
LSUR	Length of overland flow	feet	200	500	100	700	300	238-246[1]	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.035	0.02-0.04[1]	Topography
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	0.10	Land use, surface condition
RETSC	Retention/interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	0.125	Land use, surface condition
IWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
IQUAL									
ACQOP	Rate of accumulation of constituent	#/day						$1x10^7$	Land use
SQOLIM	Maximum accumulation of constituent	#						$3x10^7$	Land use
WSQOP	Wash-off rate	in/hr						1.5	Land use
RCHRES									
HYDR-PARM2									
KS	Weighting factor for hydraulic routing							0.3	
GQUAL									
FSTDEC	First order decay rate of the constituent	1/day						1.15	
THFST	Temperature correction coeff. for FSTDEC							1.05	

[1]Varies with land use

5.6.3. Lower Opequon Creek

5.6.3.a. Hydrology

Lower Opequon Creek is not gaged at the Virginia/West Virginia state line; as result, Lower Opequon Creek was not calibrated for hydrology. The Lower Opequon Creek sub-watershed B09-15 (Abrams Creek) is highly urbanized. The remaining portion of the Lower Opequon Creek watershed, the 14 sub-watersheds that comprise the Lower Opequon Remnant, is primarily rural and has a land use distribution comparable to the Upper Opequon Creek watershed. Given the similar land use distribution, and the fact that Abrams Creek was modeled as a separate unit, the decision was made to use the hydrologic parameters from the Upper Opequon Creek calibration to model the Lower Opequon Remnant.

5.6.3.b. Fecal Coliform

The water quality calibration for Lower Opequon Creek was performed at an hourly time step using the HSPF model. The water quality calibration period was September 1, 1992 through June 30, 1997. There were 4 VPDES permitted point sources and 26 general permit point sources of bacteria in the Lower Opequon Creek watershed remnant during the calibration period. Fecal coliform (FC) observations from the VADEQ ambient water quality monitoring station 1AOPE025.10 were used to calibrate the water quality component of HSPF for Lower Opequon Creek. Additional dischargers in the Upper Opequon and Abrams Creek watersheds were represented by including the output from the calibration simulations for those watersheds as point source inputs to the HSPF model for the simulation of Lower Opequon Creek. Please see the calibration descriptions of these watersheds for further details of their contributions. Output from the HSPF model was generated as an hourly time series and daily average time series of fecal coliform concentration. *E. coli* concentrations were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad (1)$$

The geometric mean was calculated on a monthly basis. The final calibration parameters are shown in Table 5.24.

The BST results for Lower Opequon Creek are shown in Table 5.22. Table 5.23 contains the simulated percent contributions from the major source categories to the in-stream load during the calibration period.

Table 5.22. Bacterial source tracking results at the Lower Opequon Creek station.

		ARA - Enterococci			
Location	**DATE**	**Wildlife**	**Human**	**Livestock**	**Cats/Dogs**
VA/WV State Line	3/23/2003	4.2%	45.8%	50.0%	0.0%
VA/WV State Line	5/21/2003	33.3%	33.3%	25.0%	8.4%
VA/WV State Line	6/11/2003	45.8%	8.3%	41.7%	4.2%

Table 5.23. Simulated percent contributions from major source categories during the calibration period: Lower Opequon Creek.

Scenario	Livestock DD	Livestock Land	Wildlife DD	Wildlife Land	Septic Systems	Cats/ Dogs	Impervious	Interflow and Groundwater	Headwaters Contributions
Total period	0.5	66.7	0.5	1.7	6.8	5.2	0.0	2.7	16.0
Periods of no rainfall	7.4	0	8.8	0	0	0	0	3.4	76.8

Because BST samples are collected periodically, the conditions under which they are collected differ over time. As a result, when comparing Table 5.22 and Table 5.23, it is appropriate to compare the BST data shown in Table 5.22 to both the "Total period" and "Periods of no rainfall" simulated percent contribution values in Table 5.23. Examining Table 5.22 and Table 5.23 shows that contributions from livestock appear to be similar to those observed in the BST data. Contributions from wildlife are underpredicted as compared to the BST data, but do fall within the range of observed values. Contributions from humans are underpredicted as compared to the BST data; contributions from cats and dogs are similar to those observed in the BST data. Considering the uncertainty associated with both the BST analysis and the modeling process, as well as the fact that the breakdown of contributions from the headwaters is not evident (which contributes 16-77% of the fecal coliform), this comparison displays and adequate representation of the situation in the Lower Opequon Creek.

The simulated fecal coliform concentrations agree well with the observed fecal coliform concentrations. Figure 5.22 shows the daily average simulated fecal coliform concentrations and the observed data. The overall maximum concentration during any given hour for the calibration period was 15,300 cfu/100 mL; the maximum concentration for the observed data during that period was at the capped value of 8,000 cfu/100 mL.

The geometric mean for the simulated data for the calibration period is 235 cfu/100 mL; the geometric mean for the observed data for the same period is 361 cfu/100 mL. However, there is a lower cap on the observed data at 100 cfu/100 mL, which may cause the observed geometric mean to be inflated. Twenty-five percent of the observed values were recorded at the lower cap of 100 cfu/100 mL.

The violation rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL matched well at 38% for the observed data and 30% for the simulated data. Because the observed samples were collected on a monthly basis, a comparison of violations of the geometric mean criterion cannot be conducted.

The final parameters used in the calibration and validation simulations are listed in Table 5.24.

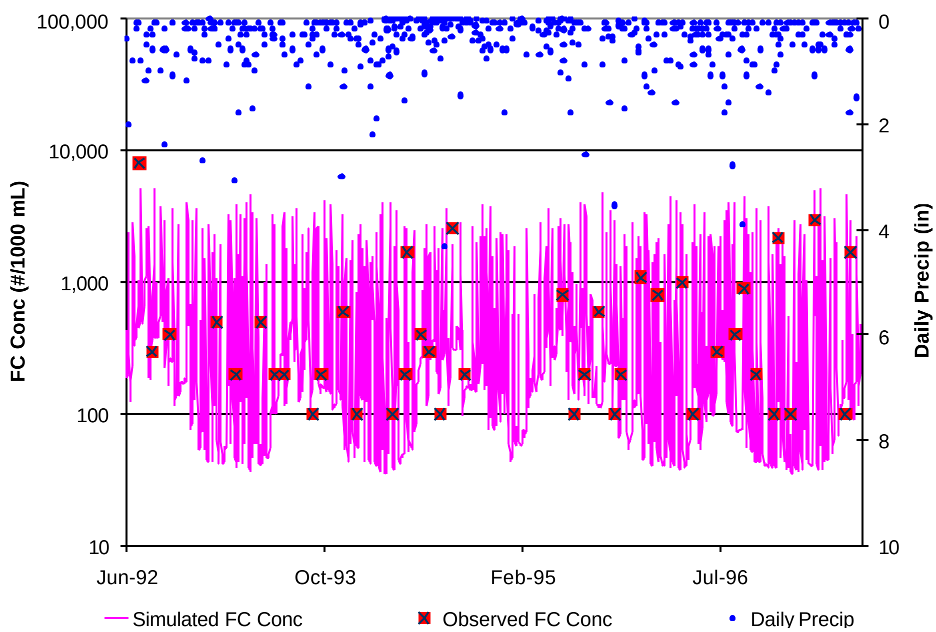

Figure 5.22. Observed and Simulated Fecal Coliform Concentrations and Rainfall In Lower Opequon Creek.

Table 5.24. Input parameters used in HSPF simulations for Lower Opequon Creek.

Parameter	Definition	Units	RANGE OF VALUES TYPICAL MIN	TYPICAL MAX	POSSIBLE MIN	POSSIBLE MAX	START	FINAL CALIB.	FUNCTION OF...
PERLND									
QUAL-INPUT									
ACQOP	Rate of accumulation of constituent	#/day						Monthly	Land use
SQOLIM	Maximum accumulation of constituent	#						Monthly	Land use
WSQOP	Wash-off rate	in/hr						2.5	Land use
IOQC	Constituent conc. in interflow	#/ft3						8496	Land use
AOQC	Constituent conc. in active groundwater	#/ft3						5664	Land use
IQUAL									
ACQOP	Rate of accumulation of constituent	#/day						$1x10^7$	Land use
SQOLIM	Maximum accumulation of constituent	#						$3x10^7$	Land use
WSQOP	Wash-off rate	in/hr						1.5	Land use
RCHRES									
GQUAL									
FSTDEC	First order decay rate of the constituent	1/day						1.15	
THFST	Temperature correction coeff. for FSTDEC							1.05	

[1]Varies with land use

CHAPTER 6: BACTERIA LOAD AND WASTELOAD ALLOCATIONS

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

6.1. Background

The objective of the bacteria TMDLs for Abrams Creek, Upper Opequon Creek, and Lower Opequon Creek was to determine what reductions in bacteria loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDL were 126 cfu/100mL (calendar-month geometric mean) and 235 cfu/100mL (single sample maximum). The TMDL considers all sources contributing *E. coli* to for Abrams Creek and Upper and Lower Opequon Creeks. The sources can be separated into nonpoint and point (or direct) sources. The incorporation of the different sources into the TMDL isdefined in the following equation:

$$TMDL = SWLA + SLA + MOS \qquad [6.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety, implicit.

While developing allocation scenarios to implement the bacteria TMDL, an implicit margin of safety (MOS) was used by using conservative estimations of all factors that would affect the bacteria loadings in the watershed (e.g., animal numbers, production rates, and contributions to streams). These factors were estimated in such a way as to represent the worst-case scenario; i.e., these factors would describe the worst stream conditions that could exist in the watershed. Creating a TMDL with these conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard violations will occur if the TMDL plan is followed.

For the Upper Opequon and Lower Opequon TMDLs, the WLA was determined as the sum of the contributions from the permitted point source dischargers in each watershed. Contributions from these sources were allocated at their permit limits. For the Abrams Creek TMDL, a clear permit limit was not defined for the MS4 areas. For this watershed, the WLA was set to the bacteria load expected to come from the MS4 areas after they have achieved reductions to the 'maximum extent practicable' (see Section 7.5.3).

The period selected for the load allocation study was July 1992 to June 1997, the period of observed data that resulted in the three watersheds being placed on the 303d Impaired Waters List. This period incorporates average rainfall, low rainfall, and high rainfall years; and the climate during this period caused a wide range of hydrologic events including both low and high flow conditions.

The calendar-month geometric mean values used in this report are geometric means of the average daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, we took the arithmetic mean of the hourly values on a daily basis, and then calculated the geometric mean from these average daily values.

The guidance for developing an *E. coli* TMDL offered by VADEQ is to develop input for the model using fecal coliform loadings as the bacteria source in the watershed. Then, VADEQ suggests the use of a translator equation they developed to convert the daily average fecal coliform concentrations output by the model to daily average *E. coli* concentrations. The translator equation is:

$$\textit{E. coli}\text{ concentration} = 2^{-0.0172} \times (\text{FC concentration}^{0.91905}) \qquad [6.2]$$

where, the bacteria concentrations (FC and *E. coli*) are in cfu/100mL.

This equation was used to convert the fecal coliform concentrations output by HSPF to *E. coli* concentrations. Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

6.2. Abrams Creek

6.2.1. Existing Conditions

To better understand the fate of bacteria from different sources, a series of model simulations were run, so that each run simulated one of the different sources in order to determine the resulting mean in-stream concentration due to each source. These results were then compared with the mean concentration from all sources to estimate the percent of the mean concentration due to each source. The results are presented for the allocation period of 1992 to 1997 in Table 6.1. As shown, NPS loadings from impervious land are the largest source of *E. coli* in the stream, accounting for almost 80% of the mean daily *E. coli* concentration. Loadings from the impervious land segments (ILS) are primarily due to pets and wildlife defecating on these surfaces, and subsequent runoff and transport of bacteria to the stream during runoff events. The next largest contributor is wildlife direct deposit, accounting for 12% of the mean daily *E. coli* concentration. NPS loading from pervious land segments (PLS) comes from manure applied to, or deposited on, cropland, pastures, and forests by livestock, wildlife, and other NPS sources (i.e., failing septic systems); loading from these sources is responsible for almost 4% of the mean daily in-stream *E. coli* concentration. While direct deposits to streams by cattle and wildlife are responsible for just over 16% of the mean daily *E. coli* concentration, these sources can have a significant impact on water quality at any given time because fecal material is deposited directly in the stream and is not subject to die-off during transport as are land applied sources. As shown in Table 6.1, nonpoint source loadings of *E. coli* on impervious surfaces result in much higher mean daily in-stream *E. coli* concentrations (≈183 cfu/100 mL) than do *E. coli* loadings from pervious upland areas (8.8 cfu/100 mL).

Table 6.1. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Abrams Creek watershed.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100mL	Relative Contribution by Source
All sources	229.9	--
Direct deposits of cattle manure to stream	9.8	4.3%
Direct nonpoint source loadings to the stream from wildlife	27.8	12.1%
Nonpoint source loadings from pervious land use segments[a]	8.8	3.8%
Nonpoint source loadings from impervious land use segments[a]	183.4	79.8%

[a]These sources only contribute to instream concentrations during runoff events.

The contribution of each of the sources listed in Table 6.1 to the mean daily *E. coli* concentration for 3 summer months during the simulation period is shown in Figure 6.1. Figure 6.1 illustrates that on days on which a runoff event occurred, (the peaks seen in Figure 6.1), the average daily concentration of *E. coli* is dominated by contributions from ILS sources – pets and wildlife (geese, etc). On days with runoff, contributions from ILS sources alone result in violation of the instantaneous standard of 235 cfu/100mL. The next most significant contributors are livestock and wildlife that deposit fecal matter directly into the stream. This source is a more significant contributor to the total in-stream *E. coli* concentration at times when no runoff is occurring. *E. coli* concentrations from pervious land surfaces (PLS) are the least significant with respect to violations of the instantaneous standard.

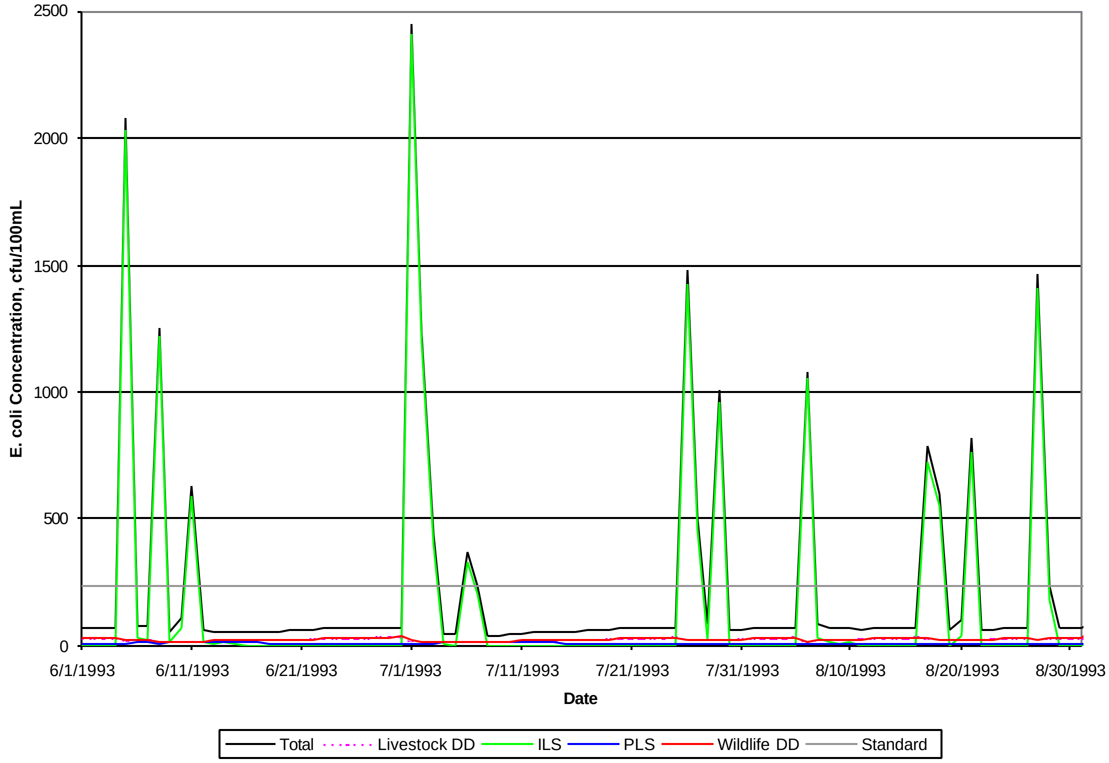

Figure 6.1. Standards violation by contributions from different *E. coli* sources for existing conditions in the Abrams Creek watershed.

The contributions from the sources listed in Table 6.1 to the calendar-month geometric *E. coli* concentration are shown in Figure 6.2. The calendar-month geometric mean value is dominated by contributions from wildlife directly depositing feces in the stream. Smaller contributions come from PLS and livestock direct deposits. Contributions from impervious land surfaces are not significant with respect to the calendar-month geometric mean because high values during runoff events are offset by very low or zero contributions during periods between runoff events.

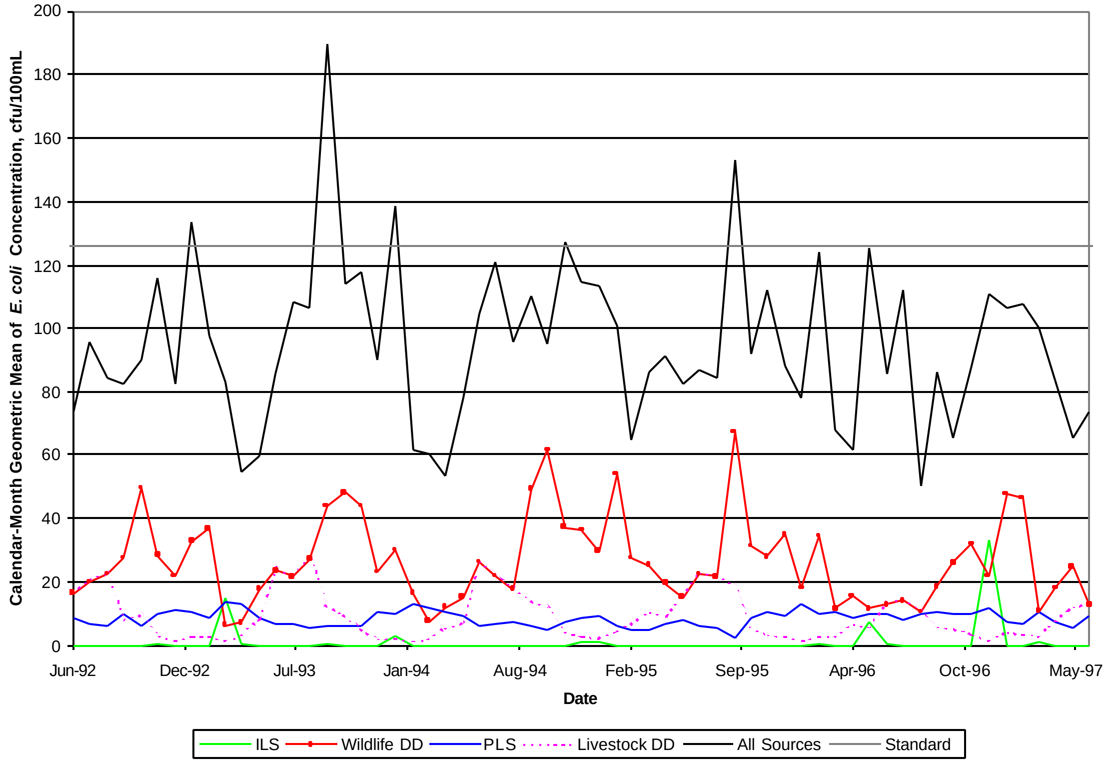

Figure 6.2. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the Abrams Creek watershed.

6.2.2. TMDL Allocation Scenarios

The Opequon Creek watershed (which includes Abrams Creek) is experiencing urban growth and development that must be accounted for in the TMDL development process. Three future land use scenarios were created based on 25%, 50%, and 100% build-out within the UDAs and ComCntrs within Frederick County (Section 3.6). Based upon experience with the rate of development in similarly urbanizing areas, the decision was made to develop the TMDL modeling scenarios assuming an anticipated 25% build-out within the UDAs and ComCntr planning zones in the Opequon Creek watershed. The reductions required to meet TMDL allocations, therefore, will be based on projected *E. coli* loads resulting from future land use distributions corresponding to the 25% build-out scenario. The land use distribution for the three considered build-out scenarios are shown by sub-watershed in Appendix B. A variety of allocation scenarios were considered to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the instantaneous limit of 235 cfu/100mL for the 25% build-out scenario. The scenarios and results are summarized in Table 6.2.

Table 6.2. Bacteria allocation scenarios for Abrams Creek watershed, using 25% build out scenario.

Scenario Number	% Violation of *E. coli* Standard		Percent Reductions to Fecal Coliform Loading from Abrams Creek Modeled Source Categories, %							
	Geometric mean	Instantaneous	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	All ILS	Forest PLS	Residential PLS
Existing Conditions	4	12	0	0	0	0	0	0	0	0
01	2	12	0	50	50	50	0	0	50	50
02	0	0	0	0	0	0	0	100	0	0
03	0	0	0	0	0	0	0	97	0	97
04	0	0.03	40	0	0	0	0	95	0	95
05	0	0	30	0	0	0	0	96	0	96

In scenario 01, contributions from pervious land segments (PLSs) were reduced by 50% and little change was seen in the violations of the standards. In scenarios 02 and 03, ILS contributions were essentially completely eliminated; both scenarios met the requirements of the standard. Because of this and the results of scenario 01, it was concluded that reductions in bacteria coming from agricultural and forestland PLSs would not be necessary to meet the standards. Several scenarios were evaluated to investigate what other source reductions could be combined with the ILS reductions such that 100% reductions would not be required from ILS areas. The fact that no reductions are required from PLS sources is consistent with the character of the Abrams Creek watershed: it is highly urbanized with few livestock. Reductions in wildlife were considered to be impractical to implement. Therefore, reductions from Cattle DD were considered (Scenarios 04 and 05). Scenario 04 reduced instantaneous standard violations to 0.03% with Cattle DD reductions of 40%. Scenario 05 was then considered, with Cattle DD reductions of 30% and 96% reductions in ILS and Residential PLS areas, and succeeded in meeting the standards with no violations. Scenario 05 shown in Table 6.2 was selected as the TMDL build-out allocation for the 25% build-out projection because it required a low reduction from Cattle DD and a less than 100% reduction from ILS and Residential PLS sources. This scenario calls for reductions in Cattle DD of 30% and loading from ILS sources of 96%. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 6.3 for the TMDL allocation (Scenario

06), along with the standards. Although it was estimated that there were no straight pipes in the watershed (Section 4.1.1.b), should any straight pipes be found during the implementation process, 100% of the straight pipes must be eliminated as they are illegally discharging fecal coliform into the stream.

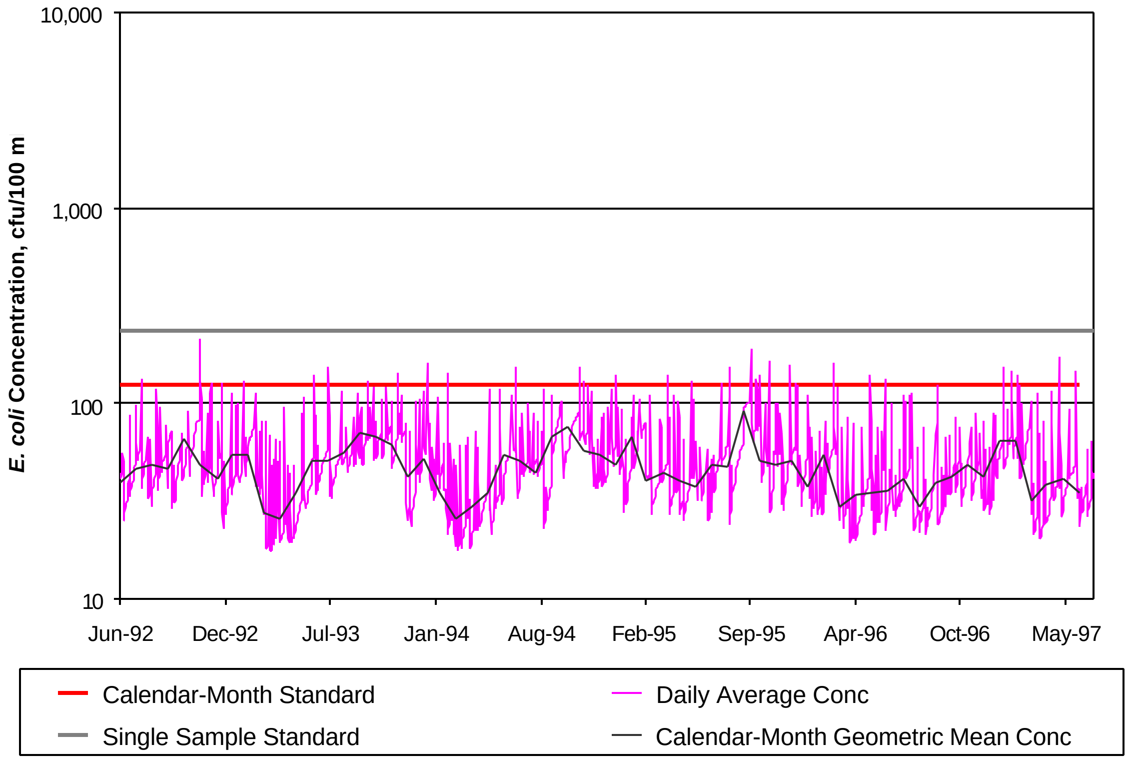

Figure 6.3. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation for 25% build-out (Allocation Scenario 05 from Table 6.2) for Abrams Creek.

Because the portions of the Abrams Creek watershed that lie within the City of Winchester are covered by one of two MS4 permits (Chapter 4) the assumption was made that the *E. coli* load originating on the portion of the impervious land segments covered by the MS4 permits (ILS MS4 Load) will be controlled by those permits. The difference between the ILS MS4 waste load allocation and the 25% build-out load is 465.6×10^{12} cfu/yr ($485 \times 10^{12} - 19.4 \times 10^{12} = 465.6 \times 10^{12}$) (Table 6.3), which is to be mitigated by MS4 regulation requiring implementation of best management practices to reduce pollutants to the "maximum extent practicable."

Table 6.3. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 05).

	Existing Condition Load (× 10^{12} cfu)	25% Build-out Load (× 10^{12} cfu)	TMDL Allocation Scenario (04) % Reduction	Future TMDL Allocation (× 10^{12} cfu)
Cattle DD	4.10	4.10	30	2.90
Wildlife DD	12.7	12.5	0	12.5
Cropland	6.6	7.1	0	7.1
Pasture	2,950	2,950	0	2,950
Residential	2,470	2,770	96	111
Loafing Lot	2,280	2,280	0	2,280
Forest	1,090	1,090	0	1,090
ILS non-MS4	257	333	96	13.3
ILS MS4[a]	451	485	96	19.4
Total	9,520	9,930	35[b]	6,490

[a]Although a NPS loading, the allocation for this sources is included in WLA of TMDL calculation.
[b]Total percent reduction includes the 465.6x10^{12} load assumed to be mitigated by MS4 regulation in the Abrams Creek watershed for the City of Winchester (VAR040053) and VDOT-Winchester Urban Area (VAR040032).

The loads presented in Table 6.3 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF predicted mean daily fecal coliform concentrations.

6.2.3. Summary of TMDL Allocation Scenario for Abrams Creek

A TMDL for bacteria has been developed for Abrams Creek. The TMDL addresses the following issues:

1. The TMDL was developed to meet the calendar-month geometric mean and instantaneous water quality standards.

2. Because *E* coli loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations for which the bacteria TMDL is based.

3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.

4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.

5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Abrams Creek watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.

6. Both the flow regime and bacteria loading to Abrams Creek are seasonal. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 30% reduction in direct deposits of cattle manure to streams and a 96% reduction in nonpoint source loadings to impervious land surfaces outside of the MS4 regulated areas, and effectively a 96% reduction of source loadings to impervious land surfaces with the MS4 regulated areas, which it is assumed will be achieved though the MS4 process. Although not estimated by our process, should any straight pipes be found during implementation, 100% of them should be removed. Using Eq. [6.1], the summary of the bacteria TMDL for Abrams Creek for the selected allocation scenario (Scenario 05) is given in Table 6.4. As directed by VADEQ, the TMDL load in Table 6.4 was determined from the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario over the simulation period. In Table 6.4, the WLA was determined by isolating the contribution of the MS4 areas to the bacteria output from the HSPF model. The LA was then determined as the TMDL – WLA.

Table 6.4. Average annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Abrams Creek bacteria TMDL.

Pollutant	SWLA	SLA	MOS	TMDL
E. coli	310×10^{10} (VAR040053 and VAR040032)	$1{,}650 \times 10^{10}$	NA	$1{,}960 \times 10^{10}$

NA – Not Applicable because MOS was implicit

6.3. Upper Opequon Creek

6.3.1. Existing Conditions

To better understand the fate of bacteria from different fecal coliform sources, a series of model simulations were run, so that each run simulated one of the different sources in order to determine the resulting mean in-stream concentration attributable to each source. These results were then compared with the mean concentration from all sources to estimate the percent of the mean concentration due to each source. The results are presented for the allocation period of 1992 to 1997 in Table 6.5. Nonpoint source loadings from pervious land segments (PLS) are the largest contributing source. NPS loading from PLS comes from manure applied to, or deposited on, cropland, pastures, and forests by livestock, wildlife, and other NPS sources (i.e., failing septic systems); loading and subsequent runoff and transport of bacteria to the stream during runoff events from these sources is responsible for more than 17% of the mean daily *E. coli* concentration. Direct deposits from cattle are the next largest contributor, accounting for 40.7% of the daily mean. The next largest contributor to the daily mean is wildlife directly depositing in the stream, accounting for 6.5%. Loadings from the impervious land segments (ILS) are primarily due to pets and wildlife defecating on these surfaces and the subsequent runoff and transport of bacteria to the stream during runoff events. ILS sources account for less than 1% of mean daily *E. coli* concentration in the stream. Point sources in the watershed contribute 2.5% to the mean daily *E. coli* concentration in the stream.

Table 6.5. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Upper Opequon watershed.

Source	Mean Daily *E. coli* Concentration by Source (cfu/100mL)	Relative Contribution by Source (%)
All sources	286.9	--
Direct deposits of cattle manure to stream	116.7	40.7
Direct nonpoint source loadings to the stream from wildlife	18.7	6.5
Nonpoint source loadings from pervious land use segments[a]	143.4	50.0
Nonpoint source loadings	0.7	0.2

from impervious land use segments[a]		
Point sources	7.3	2.5

[a]These sources only contribute to instream concentrations during runoff events.

The contributions from the sources listed in Table 6.5 to the calendar-month geometric *E. coli* concentration are shown in Figure 6.4. The calendar-month geometric mean value is dominated by contributions from cattle directly depositing feces in the stream. In-stream *E. coli* concentrations from direct nonpoint sources are highest during the summer when stream flows are lowest. This is expected because cattle spend more time in streams during the summer months; because of the low flow conditions, there is less stream flow for dilution of the direct deposit manure load. The same is true for the direct deposit from wildlife, although to a lesser extent. Deposits from cattle result in many violations of the calendar-month geometric mean goal of 126 cfu/100mL. Contributions from pervious land surfaces also cause violations of the calendar-month geometric mean goal. Contributions from impervious land surfaces and point sources are not significant with respect to the calendar-month geometric mean.

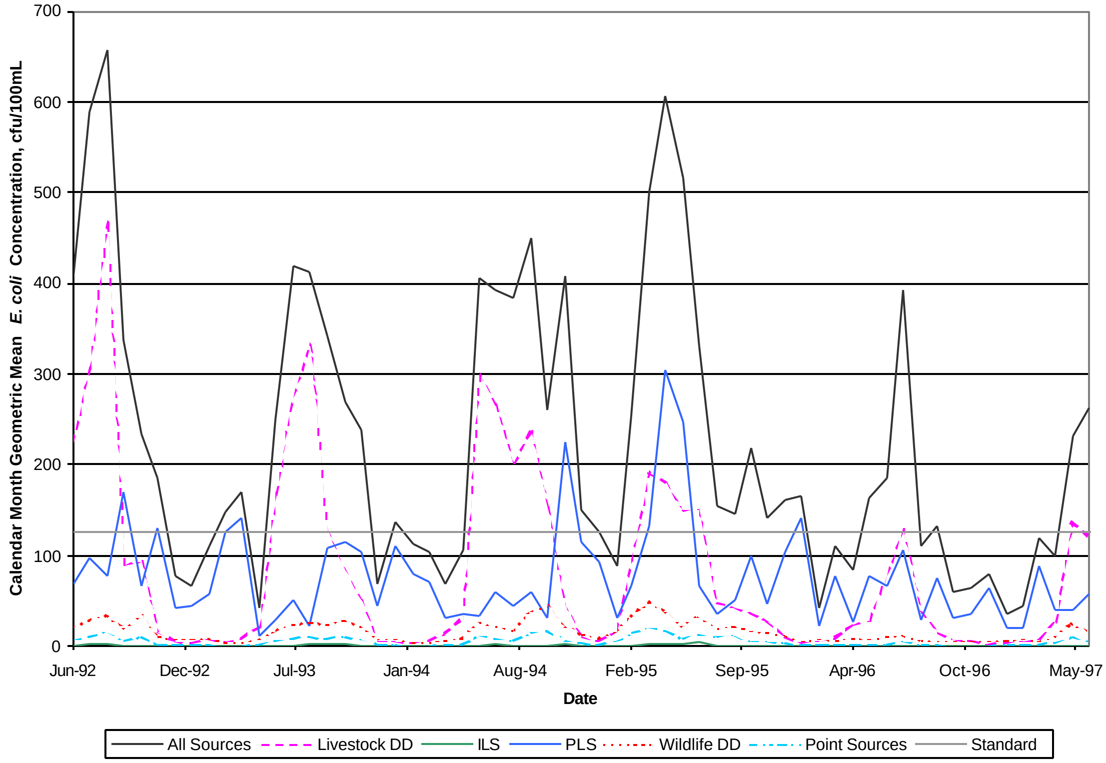

Figure 6.4. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the Upper Opequon watershed.

6.3.2. TMDL Allocation Scenarios

The Opequon Creek watershed is experiencing urban growth and development that must be accounted for in the TMDL development process. Three future land use scenarios were created based on 25%, 50%, and 100% build-out within the UDAs and ComCntrs within Frederick County (Section 3.6). Based upon experience with the rate of development in similarly urbanizing areas, the decision was made to develop the TMDL modeling scenarios assuming an anticipated 25% build-out within the UDAs and ComCntr planning zones in the Opequon Creek watershed. The reductions required to meet TMDL allocations, therefore, will be based on projected *E. coli* loads resulting from future land use distributions corresponding to the 25% build-out scenario. The land use distribution for the three considered build-out scenarios are shown by sub-watershed in Appendix B. A variety of allocation scenarios were considered to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the instantaneous limit of 235 cfu/100mL for the 25% build-out scenario. The scenarios and results are summarized in Table 6.6.

Table 6.6. Bacteria allocation scenarios for Upper Opequon watershed, using 25% build out scenario.

Scenario Number	% Violation of *E. coli* Standard		Percent Reductions to Fecal Coliform Loading from Upper Opequon Modeled Source Categories, %							
	Geometric mean	Instantaneous	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	All ILS	Forest PLS	All Residential PLS
Existing Conditions	61	43	0	0	0	0	0	0	0	0
01	44	37	50	50	50	50	50	50	50	50
02	0	0.2	100	100	100	100	0	100	0	100
03	0	0.2	99	95	95	100	99	95	0	95
04	0	0	100	95	95	100	99	95	0	95
05	0	0.1	100	90	90	100	90	90	0	90
06	0	0	100	90	90	100	95	90	0	90

In scenario 01, all contributions were reduced by 50%. This scenario reduced, but did not eliminate violations of either the geometric mean or instantaneous standard. Scenario 02 was examined to evaluate the impact of eliminating all fecal coliform sources, except wildlife. Violations of the instantaneous standard (0.2%) persisted. As discussed in the previous section, and shown in Figure 6.4, Cattle DD is a significant source in the Upper Opequon creek watershed, and as a result significant reductions from this source are necessary. In Scenario 03, contributions from both Cattle DD and Wildlife DD are both reduced by 99%. Additionally, contributions from PLS and ILS sources (except forest) are reduced by 95%. Even under this significant reduction scenario, minor but persistent standards violations occurred (instantaneous, 0.2%). In Scenario 04 Cattle DD contributions were eliminated. Although no violations occurred, the scenario was unnecessarily stringent, and therefore additional alternative scenarios were evaluated. In particular, the wildlife reductions were higher than necessary. In Scenario 05, Wildlife DD and Cropland, Pasture, Residential PLS, and ILS contributions were set to 90%, resulting in a small violation of the instantaneous standard. Because these violations came primarily from direct deposit sources, Scenario 06 was evaluated, in which the wildlife reductions were increased to 95. Scenario 06 produced no standard violations, and was selected at the final TMDL for the 25% build-out projection of Upper Opequon Creek. See Section 7.5.5 for a discussion of the practicality of 95% reductions in wildlife direct deposits. Although it was estimated that there were no straight pipes in the Upper Opequon Creek watershed (Section 4.2.1.b), should any be found during the implementation process, they should be reduced 100%, as they would be illegally discharging fecal bacteria into the stream.

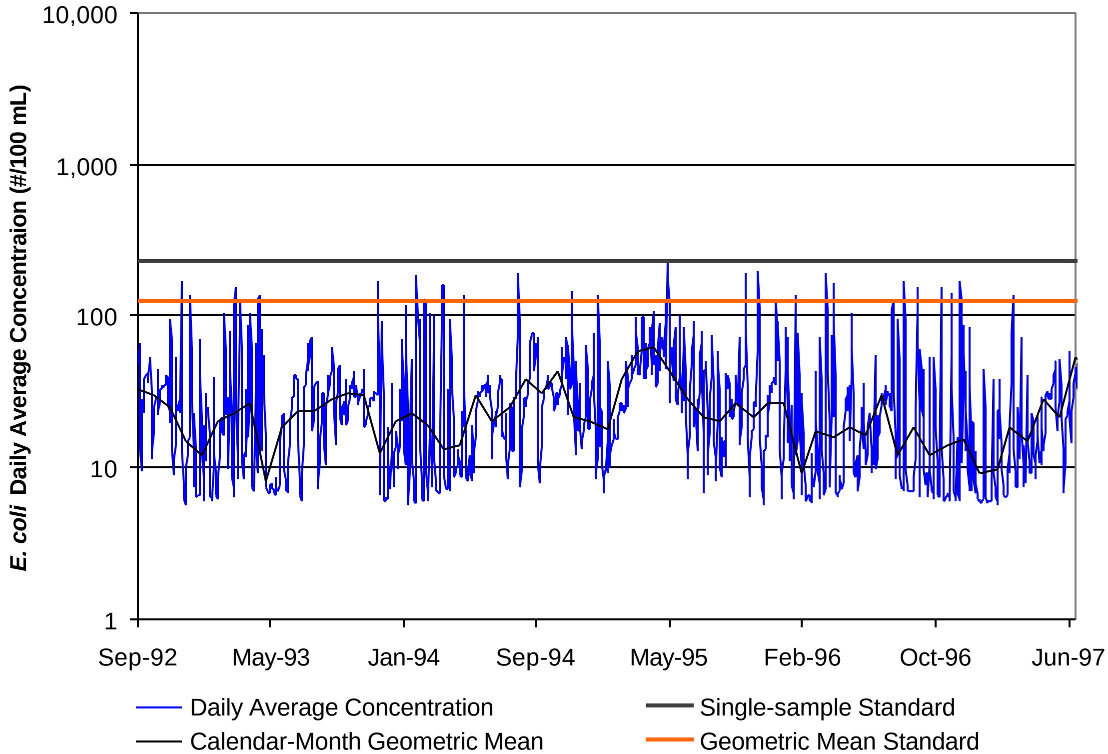

Figure 6.5. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation for 25% build-out (Allocation Scenario 06 from Table 6.6) for Upper Opequon.

Table 6.7. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 06).

	Existing Condition Load (× 10^{12} cfu)	**25% Build-out Load** (× 10^{12} cfu)	**TMDL Allocation Scenario (06)**	**Future TMDL Allocation** (× 10^{12} cfu)
Cattle DD	93.6	93.6	100	0
Wildlife DD	13.2	12.8	95	0.64
Cropland	92.3	92.6	90	9.26
Pasture	13,600	13,600	90	1360
Residential	2,030	2,580	90	258
Loafing Lot	297	297	100	0
Forest	583	583	0	583
All ILS	4.7	7.0	90	0.7
Point Sources	5.6	5.6	--	5.6
Total	16,700	17,300	87	2,200

The loads presented in Table 6.7 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF predicted mean daily fecal coliform concentrations.

6.3.3. Wasteload Allocations

The permitted dischargers in the Upper Opequon Creek watershed are listed in Table 4.1. Point sources permitted to discharge bacteria in the Upper Opequon Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES) are listed in Table 6.8. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 mL. Some have explicit permitted loads (e.g., VA0075191) to achieve this goal. Another method for achieving this goal is chlorination, as is used in VA0088722. Chlorine is added to the discharge stream at levels intended to kill off any pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations, including fecal coliform concentrations, are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, fecal coliform concentrations are reduced to levels well below the 200 cfu/100 mL limit. Therefore, the contributions from VA0088722 were explicitly modeled as 200 cfu/100 mL times the permitted flow.

Table 6.8. Point Sources Discharging Bacteria in the Upper Opequon Watershed.

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated *E. coli* Load (WLA) (cfu/year)
VA0075191	Parkins Mills STP	2.0	200 cfu/ 100 mL	5.52×10^{12}	5.52×10^{12}	3.48×10^{12}
VA0088722	Stonebrook Swim and Raquet Club	0.004	NA	NA	1.11×10^{11}	6.99×10^{10}
17 VAG permits	General Permit Facilities	0.017	200 cfu/ 100 mL	4.70×10^{8}	4.70×10^{10}	2.96×10^{10}

6.3.4. Summary of TMDL Allocation Scenario for Upper Opequon Creek

A TMDL for bacteria has been developed for Upper Opequon Creek. The TMDL addresses the following issues:

1. The TMDL was developed to meet the calendar-month geometric mean and instantaneous water quality standards.

2. Because *E* coli loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations for which the bacteria TMDL is based.

3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.

4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.

5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Upper Opequon Creek watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.

6. Both the flow regime and bacteria loading to Upper Opequon Creek are seasonal. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 100% reduction in direct deposits of feces by cattle to streams, a 95% reduction in direct deposits of feces by wildlife to streams, and a 90% reduction in nonpoint source loadings to impervious (ILS) and pervious (PLS) land surfaces, except forest. Should any straight pipes be found in the watershed during implementation, they should be reduced 100%. Using Eq. [6.1], the summary of the bacteria TMDL for Upper Opequon Creek for the selected allocation scenario (Scenario 06) is given in Table 6.9. As directed by VADEQ, the TMDL load in Table 6.9 was determined from the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario over the simulation period. In Table 6.9, the WLA was obtained by summing the products of each permitted point source's fecal coliform discharge concentration and allowable annual discharge. The LA is then determined as the TMDL – WLA.

Table 6.9. Average annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Upper Opequon bacteria TMDL.

Pollutant	SWLA	SLA	MOS	TMDL
E.coli	$357.7x10^{10}$ 17 1000 gpd units; VA0075191; VA0088722	$3,636.7x10^{10}$	NA	$3,994.4x10^{10}$

NA – Not Applicable because MOS was implicit

6.4. Lower Opequon Creek

6.4.1. Existing Conditions

To better understand the fate of bacteria from different sources, a series of model simulations were run, so that each run simulated one of the different sources in order to determine the resulting mean instream concentration due to each source. These results were then compared with the mean concentration from all sources to estimate the percent of the mean concentration due to each source. The results are presented for the allocation period of 1992 to 1997 in Table 6.10. As shown, NPS loadings from pervious land segments (PLSs) are the largest source of *E. coli* in the stream, accounting for 70% of the mean daily *E. coli* concentration. NPS loading from PLS comes from manure applied to, or deposited on, cropland, pastures, and forests by livestock, wildlife, and other NPS sources (e.g., failing septic systems). The next largest contributors are loadings from point sources and Upper Opequon Creek and Abrams Creek. See the corresponding sections for those watersheds (6.1.1, 6.1.2) for the breakdown of *E. coli* sources contributing to the watershed inputs; they account for almost 8% of the *E. coli* concentration at the watershed outlet. Direct deposits to streams by cattle and wildlife are responsible for only 12.5% of the mean daily *E. coli* concentration; typically these sources can have a significant impact on water quality at any given time because fecal material is deposited directly in the stream and is not subject to die-off during transport as are land applied sources. Most cattle in the watershed are already fenced out of the stream, which is why the contribution from livestock to the overall total is so low.

Table 6.10. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Lower Opequon watershed.

Source	Mean Daily *E. coli* Concentration by Source (cfu/100mL)	Relative Contribution by Source (%)
All sources	170.8	--
Direct deposits of cattle manure to stream	26.1	6.7
Direct nonpoint source loadings to the stream from wildlife	10.0	5.8
Nonpoint source loadings from pervious land use segments[a]	119.6	70.0
Nonpoint source loadings from impervious land use segments[a]	0.3	0.2
Point sources	16.4	9.6
Loadings from Upper Opequon Creek and Abrams Creek	13.1	7.6

[a]These sources only contribute to instream concentrations during runoff events.

The contributions from the sources listed in Table 6.10 to the calendar-month geometric *E. coli* concentration are shown in Figure 6.6. The calendar-month geometric mean value has significant contributions from all sources except ILS (which have been removed from Figure 6.6). The PLS contributions appear underrepresented in the figure because of low PLS contribution between runoff events lowers the geometric mean.

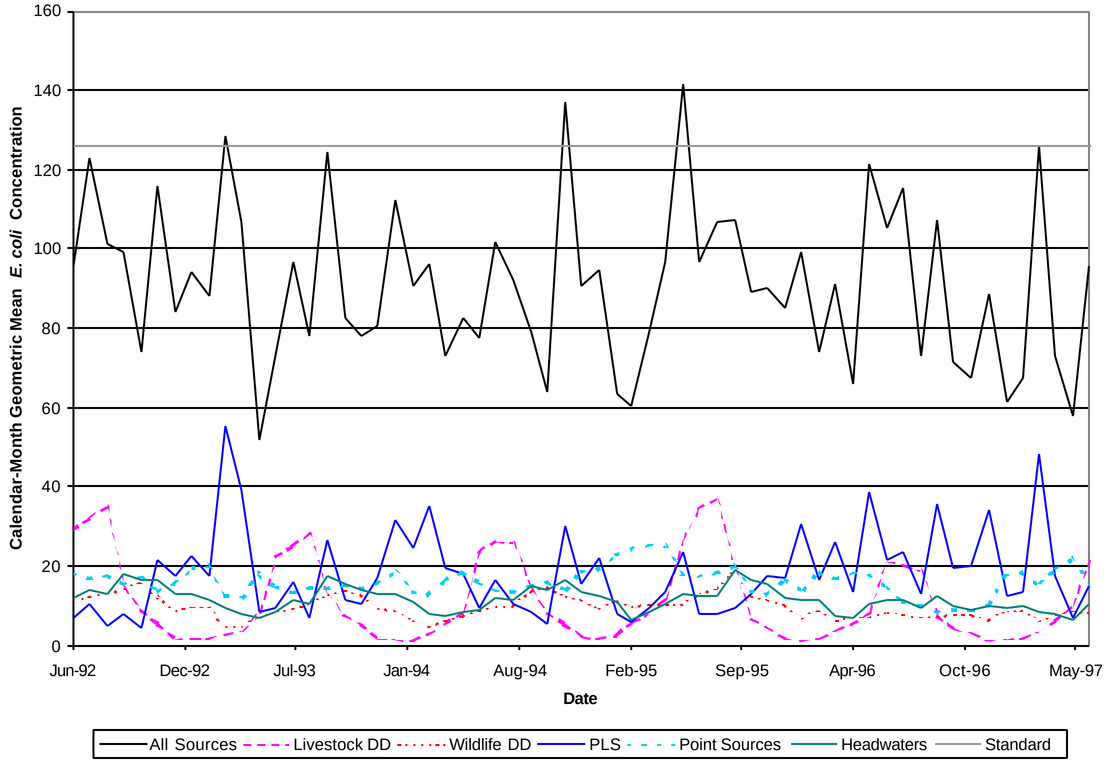

Figure 6.6. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the Lower Opequon watershed.

6.4.2. TMDL Allocation Scenarios

The Opequon Creek watershed is experiencing urban growth and development that must be accounted for in the TMDL development process. Three future land use scenarios were created based on 25%, 50%, and 100% build-out within the UDAs and ComCntrs within Frederick County (Section 3.6). Based upon experience with the rate of development in similarly urbanizing areas, the decision was made to develop the TMDL modeling scenarios assuming an anticipated 25% build-out within the UDAs and ComCntr planning zones in the Opequon Creek watershed. The reductions required to meet TMDL allocations, therefore, will be based on projected *E. coli* loads resulting from future land use distributions corresponding to the 25% build-out scenario. The land use distribution for the three considered build-out scenarios are shown by sub-watershed in Appendix B. A variety of allocation scenarios were considered to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the instantaneous limit of 235 cfu/100mL for the 25% build-out scenario. The scenarios and results are summarized in Table 6.11.

Table 6.11. Bacteria allocation scenarios for Lower Opequon watershed, using 25% build out scenario.

	% Violation of *E. coli* Standard		Percent Reductions to Fecal Coliform Loading from Lower Opequon Modeled Source Categories, %							
Scenario Number	Geometric mean	Instantaneous	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	All ILS	Forest PLS	All Residential PLS
Existing conditions + ABR and Upper OPE reductions	2.1	9.7	0	0	0	0	0	0	0	0
01	0	9.6	90	0	0	0	0	0	0	0
02	0	2.2	0	80	80	100	0	25	0	75
03	0	0.1	75	95	95	100	75	70	0	70
04	0	0.2	0	95	95	100	0	70	0	70
05	0	0	0	95	95	100	0	80	0	80

The initial scenario in Table 6.11 reflects the violations that occur if the reductions from Abrams Creek and Upper Opequon Creek are used in generating the point source input from these two sources for the model. Scenario 01 calls for a 90% reduction from cattle, however, this reduction produces an almost unnoticeable change in violations of the instantaneous standard. Therefore, reductions from cattle direct deposits were deemed unnecessary for the final TMDL allocation. This reflects the fact that many farmers in the Lower Opequon Creek Watershed remnant have already fenced their cows out of the stream. Scenarios 02-05 took incremental reductions in the PLS and ILS sources to determine the minimum reductions necessary to meet water quality standards. Comparison of scenarios 03 and 04 shows that direct contributions from wildlife sources are also not significant contributors to the *E. coli* concentrations in the Lower Opequon remnant. The final scenario shown in Table 6.11, Scenario 05, was selected as the TMDL build-out allocation for the 25% build-out projection because it met the water quality standards while requiring the fewest reductions from the nonpoint sources. This scenario calls for reductions in PLS loadings of 95% for cropland and pastures and 100% for loafing lots. The scenario also calls for a reduction in loading from ILS sources and residential PLS sources of 80%. Although it was estimated that there are no straight pipes discharging from houses into the Lower Opequon Creek (Section 4.3.1.b), should any be found during implementation, they must be completely eliminated (i.e., 100% reduction), as they would be illegally discharging fecal bacteria into the stream. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 6.7 for the TMDL allocation (Scenario 05), along with the standards.

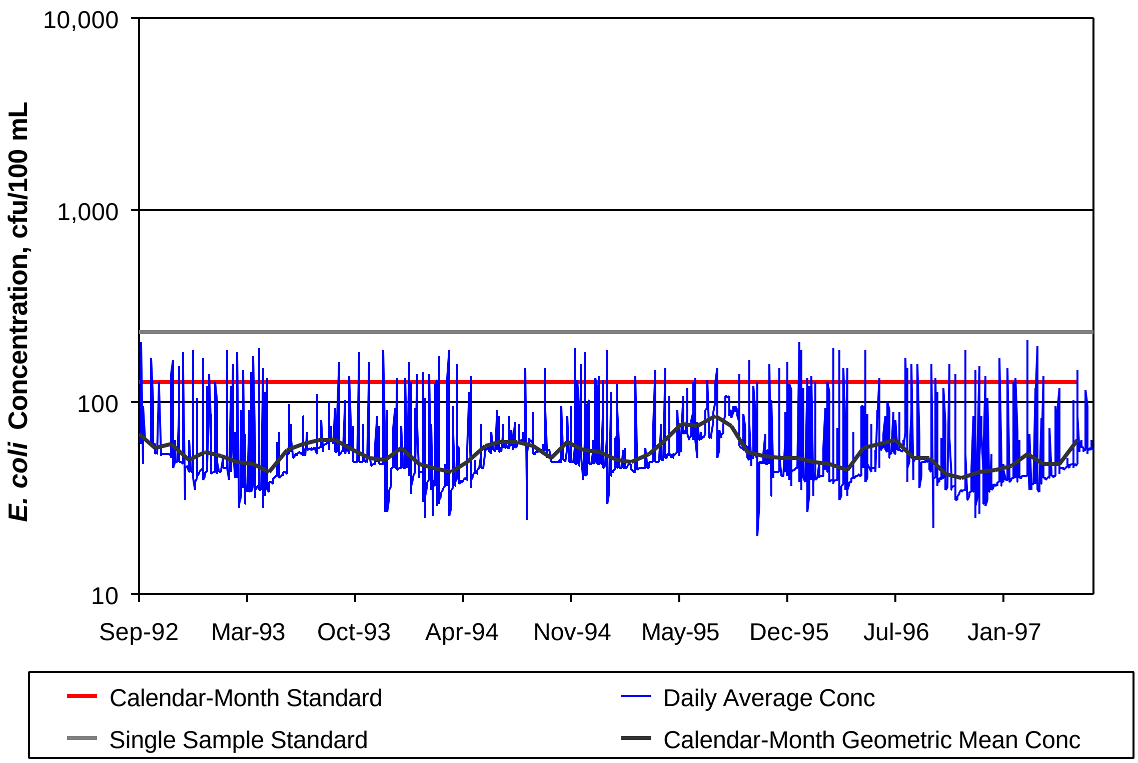

Figure 6.7. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation for 25% build-out (Allocation Scenario 05 from Table 6.11) for Lower Opequon.

The loads presented in Table 6.12 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF predicted mean daily fecal coliform concentrations.

Table 6.12. Annual fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 05).

	Existing Condition Load (× 10^{12} cfu)	25% Build-out Load (× 10^{12} cfu)	TMDL Allocation Scenario (05) % Reduction	Future TMDL Allocation (× 10^{12} cfu)
Cattle DD	16.2	16.2	0	16.2
Wildlife DD	1.8	1.7	0	1.7
Cropland	205	205	95	10.3
Pasture	21,300	21,300	95	1,070
Residential	1,300	1,430	80	286
Loafing Lot	966	966	100	0
Forest	592	593	0	593
All ILS	3.90	6.55	70	1.97
Point Sources	33.8	33.8	--	33.8
Total	24,400	24,600	92	2,000

6.4.3. Wasteload Allocations

The permitted dischargers in the Lower Opequon Creek watershed are listed in Table 4.1. Point sources permitted to discharge bacteria in the Lower Opequon Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES) are listed in Table 6.13. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 mL. Some have explicit permitted loads (e.g., VA0065552) to achieve this goal. Another method for achieving this goal is chlorination, as is used in VA0023116. Chlorine is added to the discharge stream at levels intended to kill off any pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations, including fecal coliform concentrations, are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, fecal coliform concentrations are reduced to levels well below the 200 cfu/100 mL limit. Therefore, the contributions from VA0023116 were explicitly modeled as 200 cfu/100 mL times the permitted flow.

Table 6.13. Point Sources Discharging Bacteria in the Lower Opequon Watershed.

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated *E. coli* Load (WLA) (cfu/year)
VA0065552[a]	Opequon Region AWT	12.2[a]	200 cfu/ 100 mL	3.37×10^{13}	3.37×10^{13}	2.12×10^{13}
VA0023116	I-81 Rest Area STP	0.015	NA	NA	4.15×10^{10}	2.61×10^{10}
26 VAG permits	General Permits	0.026	200 cfu/ 100 mL	7.19×10^{10}	7.19×10^{10}	4.53×10^{10}

[a]Located above the Abrams and Opequon confluence, but discharges into the Lower Opequon. Design flow is 8.4 MGD for June-November and 16 MGD for December – May, the average is 12.2 MGD

6.4.4. Summary of TMDL Allocation Scenario for Lower Opequon Creek

A TMDL for bacteria has been developed for Lower Opequon Creek. The TMDL addresses the following issues:

1. The TMDL was developed to meet the calendar-month geometric mean and instantaneous water quality standards.

2. Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations on which the bacteria TMDL is based.

3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.

4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.

5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Lower Opequon watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.

7. Both the flow regime and bacteria loading to Lower Opequon Creek are seasonal. The TMDL accounts for these seasonal effects.

The selected bacteria TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 95% reduction in contributions from cropland and pastures, a 100% reduction in contributions from loafing lots, and an 80% reduction in nonpoint source loadings to impervious land surfaces and residential PLSs. Should any straight pipes be found during implementation, they also must be reduced 100%. Using Eq. [6.1], the summary of the bacteria TMDL for Lower Opequon for the selected allocation scenario (Scenario 05) is given in Table 6.14. As directed by VADEQ, the TMDL load in Table 6.14 was determined from the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario over the simulation period. In Table 6.14, the WLA was obtained by summing the products of each permitted point source's fecal coliform discharge concentration and allowable annual discharge. The LA was then determined as the TMDL – WLA. The TMDL for the remnant reflects only the allocated generation in the Lower Opequon watershed remnant, not including Abrams Creek. See Section 6.2.3 and Table 6.2 for details on the TMDL for Abrams Creek.

Table 6.14. Average annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Lower Opequon bacteria TMDL.

	Pollutant	SWLA	SLA	MOS	TMDL
Remnant	*E. coli*	213.0×10^{11} 26 1000 gpd units; VA0065552; VA0023116	948.1×10^{11}	NA	$1{,}161.1 \times 10^{11}$

NA – Not Applicable because MOS was implicit

CHAPTER 7: TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

7.1. TMDL Implementation Process

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on Opequon Creek and Abrams Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful execution of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

7.2. Phased Implementation and Follow-Up Monitoring

7.2.1. Staged Implementation

In general, Virginia intends for the required bacteria source reductions to be implemented in an iterative process that first addresses those sources with the greatest impact on water quality. For example, in agricultural areas of the watershed, the most promising best management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

7.3. Stage 1 Scenarios

The goal of the stage 1 scenarios is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the instantaneous criterion (235 cfu/100mL) are less than 10 percent. The stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. A margin of safety was not used in determining the stage 1 scenarios. It was estimated for modeling purposes that there are no straight pipes in any of the Opequon watersheds. Should any be found during the implementation process, they should be eliminated as soon as possible since they would be illegally discharging fecal bacteria into Opequon Creek and its tributaries.

7.3.1. Abrams Creek Scenario

Several scenarios for Abrams Creek reduced violations to less than 10% (Table 7.1). The final scenario selected for Stage 1 implementation (Scenario 05) requires no reduction in direct deposits from wildlife to streams. It requires no reduction from any PLS. It requires a 20% reduction in contributions from cattle directly to streams. Scenario 5 was chosen because it required fewer reductions from cattle and more reductions from ILS compared to other scenarios that achieve the less than 10% violation rate criteria. It is expected that the new MS4 regulation will decrease the ILS contributions within the MS4 areas by more than 60%, but 60% was set as a conservative Stage 1 implementation goal for the entire ILS area (MS4 and non-MS4) in the watershed. By requiring a 60% reduction from ILSs, fewer reductions were required from cattle in streams. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use are presented in Table 7.2 and for direct nonpoint sources in Table 7.3. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 05 fecal coliform loads are presented graphically in Figure 7.1.

Table 7.1. Allocation scenarios for Stage 1 TMDL implementation for Abrams Creek

Scenario Number	Single Sample % Violation	% Reduction Required						
		Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	ILS	All Residential PLS
01	7	20	0	0	0	0	70	0
02	8	30	0	0	0	0	60	0
03	9	40	0	0	0	0	50	0
04	8	25	0	0	0	0	60	0
05	8	20	0	0	0	0	60	0

Table 7.2. Annual nonpoint source load reductions for Stage 1 TMDL Implementation Scenario for the Abrams Creek watershed (Scenario 05).

Land use Category	Existing Conditions		Implementation Scenario	
	Existing load ($\times 10^{12}$ cfu)	25% Build-out load	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from build-out load
Cropland	6.6	7.1	7.1	0
Pasture	2,950	2,950	2,950	0
Residential[a]	2,470	2,770	2,770	0
Loafing Lot	2,280	2,280	2,280	0
Forest	1,090	1,090	1,090	0
ILS	708	818	327	60%
Total	9,485	9,885	9,312	6%

[a] Includes loads applied to both High and Low Density Residential and Urban areas

Table 7.3. Required direct nonpoint source fecal coliform load reductions for Stage 1 Implementation Scenario (Scenario 05).

Source	Existing Condition		Implementation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	25% Build-out load	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from build-out load
Cattle in streams	4.1	4.1	3.3	20%
Wildlife in Streams	12.7	12.5	12.5	0%
Total	16.8	16.6	15.8	5%

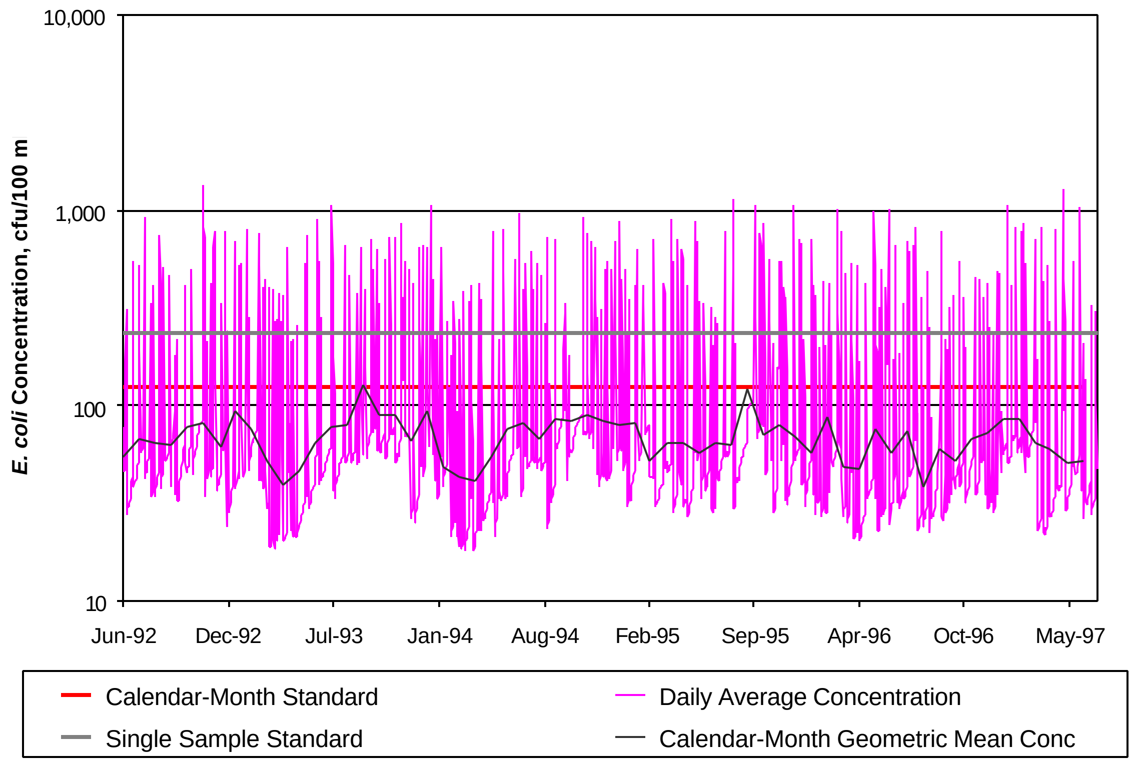

Figure 7.1. Stage 1 TMDL implementation scenario for Abrams Creek.

7.3.2. Upper Opequon Creek Scenario

Several scenarios for Upper Opequon Creek were considered to eliminate required reductions from wildlife and reduce instantaneous standards violations to 10%. The final scenario selected for Stage 1 implementation, Scenario 04 (Table 7.4) specifies an 87% reduction in direct deposits by cattle to streams and reductions (80%) in loadings from cropland and pastures. No reduction in wildlife deposits to the stream is required. A 100% reduction in loafing lot loads is required along with an 80% reduction in loads from residential areas. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenarios by land use for nonpoint sources are presented in Table 7.5 and for direct nonpoint sources in Table 7.6. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 04 fecal coliform loads are presented in Figure 7.2.

Table 7.4. Allocation scenarios for Stage 1 TMDL implementation for the Upper Opequon Creek Watershed

Scenario Number	Single Sample % Violation	% Reduction Required						
		Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	ILS	Residential PLS
01	4	95	80	80	100	0	80	80
02	19	75	75	75	100	0	75	75
03	12	85	80	80	100	0	80	80
04	10	87	80	80	100	0	80	80

Table 7.5. Annual nonpoint source load reductions for Stage 1 TMDL Implementation Scenario for the Upper Opequon Creek watershed (Scenario 03).

Land use Category	Existing Conditions		Implementation Scenario	
	Existing load ($\times 10^{12}$ cfu)	25% Build-out load	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from build-out load
Cropland	92.4	92.6	18.5	80%
Pasture	13,600	13,600	2,720	80%
Residential[a]	2,030	2,580	516	80%
Loafing Lot	297	297	0	100%
Forest	583	583	583	0%
ILS	4.7	7.0	1.4	80%
Total	16,398.1	16,949.8	3834	77.4

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 7.6. Required direct nonpoint source fecal coliform load reductions for Stage 1 Implementation Scenario (Scenario 04).

Source	Existing Condition		Implementation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	25% Build-out load ($\times 10^{12}$ cfu)	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load (%)
Cattle in streams	93.6	93.6	4.68	95
Wildlife in Streams	13.2	12.8	12.8	0
Total	106.8	106.4	17.5	83.6

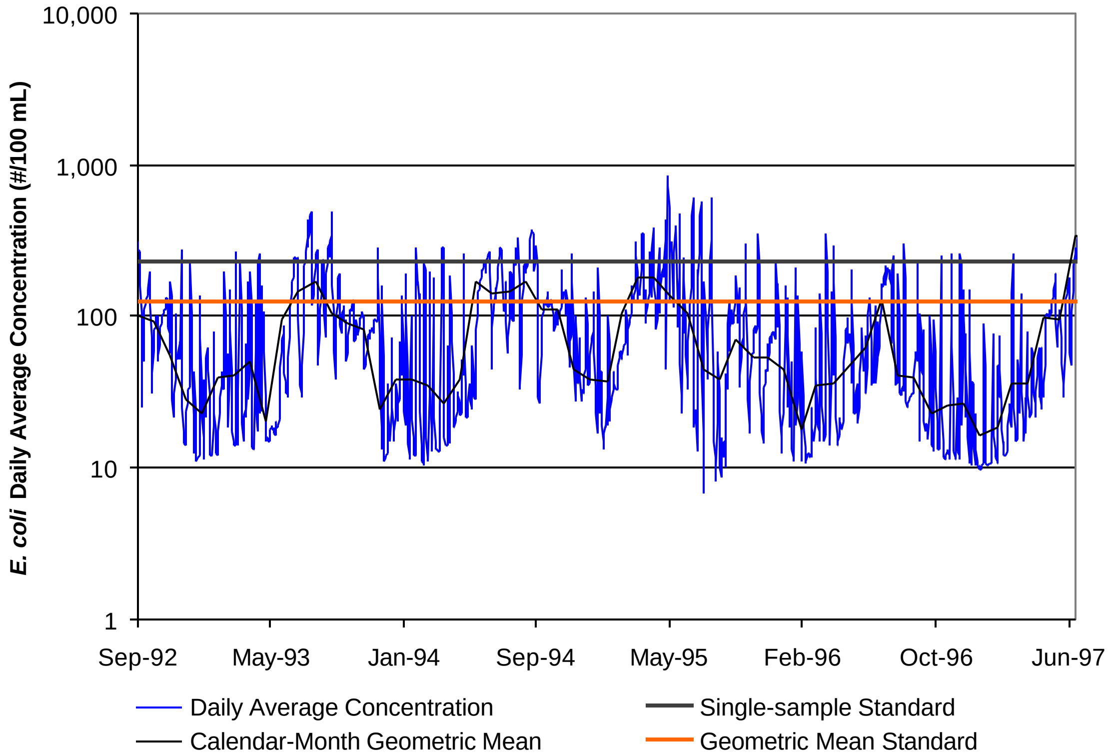

Figure 7.2. Stage 1 TMDL implementation scenario for Upper Opequon Creek.

7.3.3. Lower Opequon Creek Scenario

Several scenarios for Lower Opequon Creek reduced violations to less than 10% (Table 7.7). The first scenario in Table 7.7 reflects the violation rate when the Stage 1 implementation plans for Upper Opequon Creek and Abrams Creek have been implemented.

The final scenario selected for Stage 1 implementation (Scenario 03) requires no reduction in direct deposits by cattle or wildlife to streams, reductions (50%) in loadings from cropland and pastures, reductions (100%) in loafing lots, and a 40% reduction in contributions from ILS and residential PLS. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use are presented in Table 7.8 and for direct nonpoint sources in Table 7.9. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 03 fecal coliform loads are presented graphically in Figure 7.3.

Table 7.7. Allocation scenarios for Stage 1 TMDL implementation for Lower Opequon Creek Watershed Remnant

Scenario Number	Single Sample % Violation	% Reduction Required						
		Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	ILS	All Residential PLS
01	12	0	0	0	0	0	0	0
02	8	0	80	80	100	0	75	75
03	9	0	50	50	100	0	40	40

Table 7.8. Annual nonpoint source load reductions for Stage 1 TMDL Implementation Scenario for Lower Opequon Creek watershed remnant (Scenario 03).

Land use Category	Existing Conditions		Implementation Scenario	
	Existing load ($\times 10^{12}$ cfu)	25% Build-out load	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from build-out load
Cropland	205	205	103	50%
Pasture	21,300	21,300	10,700	50%
Residential[a]	1,300	1,430	858	40%
Loafing Lot	966	966	0	100%
Forest	592	593	593	0%
ILS	3.90	6.55	3.93	40%
Total	24,400	24,500	12,300	50%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 7.9. Required direct nonpoint source fecal coliform load reductions for Stage 1 Implementation Scenario (Scenario 03).

Source	Existing Condition		Implementation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	25% Build-out load	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from build-out load
Cattle in streams	16.2	16.2	16.2	0%
Wildlife in Streams	1.8	1.7	1.7	0%
Total	18.0	17.9	17.9	0%

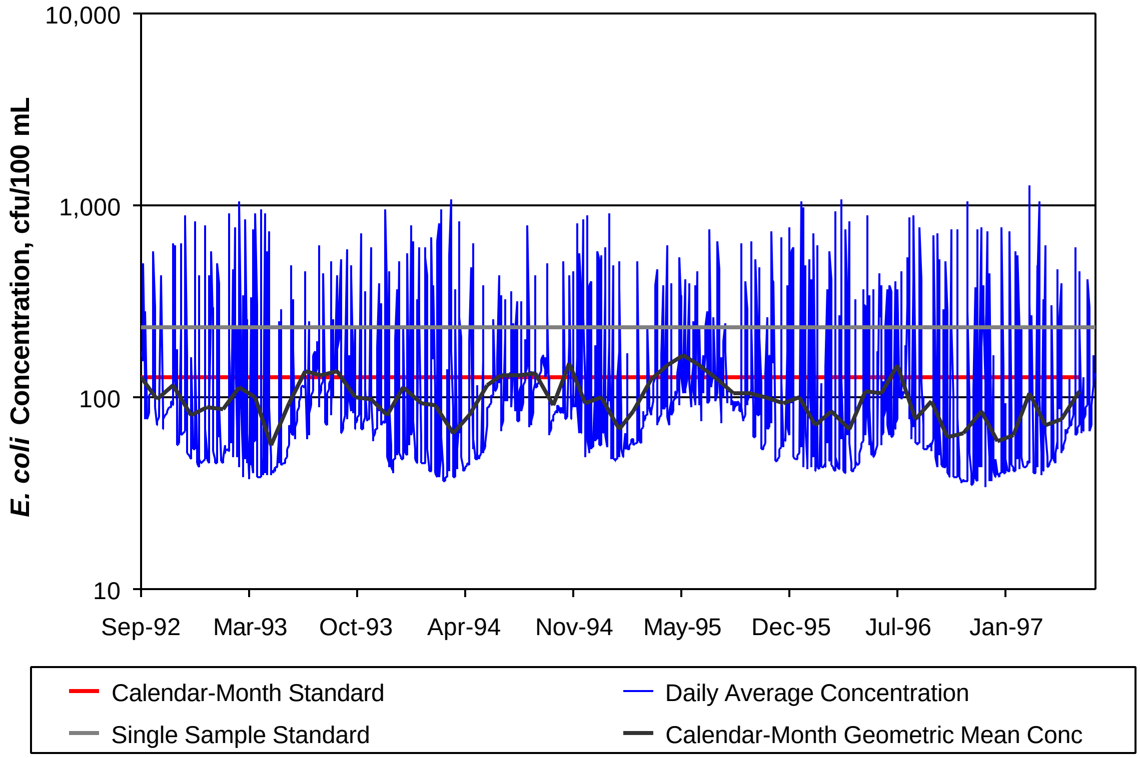

Figure 7.3. Stage 1 TMDL implementation scenario for Lower Opequon Creek.

7.4. Link to ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at .restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the Commonwealth of Virginia Shenandoah and Potomac River Basins Tributary Nutrient Reduction Strategy. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. (VASNR, 1996). A new tributary strategy is currently being developed for the Shenandoah-Potomac River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. Up-to-date information can be found at the tributary strategy web site under http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm.

7.5. Reasonable Assurance for Implementation

7.5.1. Follow-up Monitoring

VADEQ will continue monitoring Abrams Creek (1AABR000.78), Upper Opequon Creek (1AOPE036.13), and Lower Opequon Creek (1AOPE025.10) in accordance with its ambient monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards.

The monitoring station on Upper Opequon Creek (1AOPE036.13) is a trend station and will continue to be monitored on a monthly basis. The other stations are watershed stations with bi-monthly monitoring for a two-year period occurring every six years.

7.5.2. Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean

Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

7.5.3. Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for storm water discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when:…(2) Numeric effluent limitations are infeasible,…".

Part of the Abrams and Opequon Creek watersheds is covered by Phase II VPDES permits VAR040053 and VAR040032 for the small municipal separate storm sewer systems (MS4s) owned by the City of Winchester and the Virginia Department of Transportation (VDOT), respectively. These permits were issued on December 9, 2002. The City of Winchester's effective date of coverage is March 12, 2003, and VDOT's effective date of coverage is June 24, 2003. The permits state, under Part II.A., that the "permittee must develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law."

The permit also contains a TMDL clause that states: "If a TMDL is approved for any waterbody into which the small MS4 discharges, the Board will review the TMDL to determine whether the TMDL includes requirements for control of storm water discharges. If discharges from the MS4 are not meeting the TMDL allocations, the Board will notify the permittee of that finding and may require that the Storm Water Management Program required in Part II be modified to implement the TMDL within a timeframe consistent with the TMDL."

For MS4/VPDES general permits, DEQ expects revisions to the permittee's Stormwater Pollution Prevention Plans to specifically address the TMDL pollutants of concern. DEQ anticipates that BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. DEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 7.4.5 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from water quality standards change on Abrams and Opequon Creek would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

Additional information on Virginia's Storm Water Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.deq.state.va.us/water/bmps.html.

7.5.4. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

7.5.5. Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. As is the case for Upper Opequon Creek, these streams may not be able to attain standards without some reduction in wildlife load. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new “secondary contact” category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for “secondary contact recreation” which means “a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)”. These new criteria will become effective pending EPA approval and can be found at http://www.deq.state.va.us/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a stage 1 implementation scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 7.2 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

CHAPTER 8: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development process in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In February of 2003, members of the Virginia Tech TMDL group traveled to Frederick County to become acquainted with Abrams Creek watershed. The Virginia Tech TMDL group also traveled to Fredrick and Clarke Counties in March of 2003 to become acquainted with Upper and Lower Opequon watersheds. During those trips, the members of the group spoke with various stakeholders. In addition, personnel from Virginia Tech, the Lord Fairfax Soil and Water Conservation District (SWCD), and the Natural Resource Conservation Service (NRCS) visited some watershed residents and contacted others via telephone, and met with Winchester City officials to acquire their input and collect additional information. The first public meeting for Abrams Creek was held on March 13, 2003, at Shenandoah University in Winchester, VA, to inform the stakeholders about TMDL development process and to obtain feedback on animal numbers in the watershed and fecal production estimates. Approximately 45 stakeholders attended this meeting. Copies of the presentation materials and Virginia Cooperative Extension publications discussing the development of the TMDL were available for public distribution at the meeting. The public comment period for information shared at this meeting ended on April 13, 2003.

The first public meeting to discuss the impairments on the Upper and Lower Opequon Creeks was held on April 3, 2003, at Shenandoah University in Winchester, VA, to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers and fecal coliform production estimates in the watershed. Approximately 45 stakeholders attended this meeting. Copies of the presentation materials and Virginia Cooperative Extension publications discussing the development of the TMDL were available for public distribution at the meeting. The public comment period for information shared at this meeting ended on May 3, 2003. After consulting with DEQ, the decision was made to separate the TMDL reports on Abrams Creek and the Upper and Lower Opequon into two reports. One to address the benthic impairments on Abrams Creek and Lower Opequon, and the other to address the bacteria impairment on Abrams Creek and the Upper and Lower Opequon. As a result, the final public meeting to discuss the bacteria impairment included all three watersheds.

The final public meeting to discuss the bacteria impairments was public noticed on June, 24, 2003 and held on July 8, 2003 at Shenandoah University in Winchester, VA to present the draft TMDL report and solicit comments from stakeholders. Approximately 11 people attended the final meeting. Copies of the presentation materials and Virginia Cooperative Extension publications discussing the development of the TMDL were available for public distribution at the meeting. The public comment period ended on August 8, 2003. A summary of the questions and answers discussed at the meeting was prepared and is located at the VADEQ Valley Regional Office in Harrisonburg, VA.

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Appendix A
Glossary of Terms

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels

Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking

A collection of scientific methods used to track sources of fecal coliform.

Calibration

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot} x_n$$

where *n* is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model

Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Appendix B
Projected Land use for Build-out Predictions

Table B. 1. Projected Land-use for the Abrams Creek watershed for 25% build-out

Subwatersheds	Land Use						
	Commercial/ Industrial	Cropland	Forest	High Density Residential	Pasture 1	Pasture 2	Rural Residential
ABR-01	22.2	0	33.8	0	26.8	1.3	3.1
ABR-02	93.4	0	253.2	134.5	109.1	89.8	227.1
ABR-03	0	0	108.2	84.3	105.5	14.2	77.1
ABR-04	18.8	0	78.9	100.5	49.9	25.4	19.3
ABR-05	0	0	32.3	100.9	32.5	1.8	5.1
ABR-06	289.3	0	121.2	330.9	27.9	19.0	237.1
ABR-07	175.4	0	269.6	695.9	107.7	45.8	352.2
ABR-08	482.1	0	77.5	404.3	12.0	0	216.0
ABR-09	799.4	22.8	249.5	474.7	166.2	14.3	399.9
ABR-10	226.9	413.2	717.3	190.1	838.7	113.4	200.5
ABR-11	223.1	285.4	302.3	434.7	388.9	2.4	108.3

Table B. 2. Projected Land-use for the Upper Opequon watershed for 25% build-out.

Subwatersheds	Land Use									
	Commercial/ Industrial	Cropland	Farmstead	Forest	High Density Residential	Loafing Lot	Pasture 1	Pasture 2	Pasture 3	Rural Residential
B08-01	14.3	0	0	9.3	0	0	21.0	0.2	0	0
B08-02	48.2	23.2	0.5	193.4	0	0	311.6	19.3	0	5.5
B08-03	17.5	18.1	0.7	287.4	0	0	134.3	75.2	1.6	379.4
B08-04	0	0	0.6	78.0	0	0	59.8	9.3	0	21.1
B08-05	8.4	47.9	7.6	368.0	0	0	966.1	130.3	15.1	15.2
B08-06	14.4	3.4	8.2	438.7	0	0	435.5	43.5	8.2	280.6
B08-07	359.8	0.1	0.4	779.3	3.4	0	457.8	117.7	0	612.8
B08-08	72.2	76.5	6.0	670.3	0.0	0	594.5	336.6	9.9	6.0
B08-09	499.9	193.4	7.6	1024.5	69.5	0	904.7	26.3	10.4	713.4
B08-10	35.4	348.1	17.5	877.0	0	2.7	1442.9	359.2	3.5	55.5
B08-11	24.4	22.4	2.4	494.0	0	0	919.5	85.6	7.2	44.8
B08-12	197.6	124.4	30.0	984.1	117.2	0	1725.2	312.1	0.0	629.5
B08-13	730.0	311.8	18.7	1156.0	52.7	0	1467.4	206.8	6.9	584.4
B08-14	100.0	0	3.6	402.4	58.2	0	305.2	53.2	0.0	728.6
B08-15	54.7	520.3	26.8	1603.4	0	0	1914.0	278.5	8.6	268.3
B08-16	128.1	232.3	17.2	1823.4	0	0	2526.2	122.3	0	258.8

Table B. 3. Projected Land-use for the Lower Opequon watershed for 25% build-out.

Subwatersheds	Land Use									
	Commercial/ Industrial	Cropland	Farmstead	Forest	High Density Residential	Loafing Lot	Pasture 1	Pasture 2	Pasture 3	Rural Residential
B09-01	189.3	289.1	18.1	1182	0	0	2000.7	116.7	1.7	109.5
B09-02	0	60.2	5.5	456.2	0	0	802.6	160	0	13.4
B09-03	0	307.7	18.2	1541.2	0	0	2383.7	327.6	11.3	9.3
B09-04	0.7	313.2	20	192	0	0	921.2	23.4	0	0.9
B09-05	70.4	138	6.9	563.3	0	0	742.1	30.5	0	58.3
B09-06	663.3	258.8	23.1	1297.3	0	1.1	2491.4	212.7	72.5	331.2
B09-07	91	32.2	4.4	584.5	0	0	1176.7	24.4	0	60.1
B09-08	412.3	31.3	6.6	1057	0	0	1860.9	76.9	0.1	184.6
B09-09	17.6	312.8	18.6	1199.2	4.3	0	1385	72.5	0	429.1
B09-10	0	0	5.1	671.9	0	0	530.5	78	0	222.6
B09-11	71.1	438.7	30.3	1599.2	0	0	3854.6	598.1	30.1	166.6
B09-12	6	0	0	45.7	0	0	44.4	31.2	0	5.5
B09-13	993	43.5	5.9	1187	65.1	0	1008.8	197	15.7	992.5
B09-14	1.2	0	0	48.6	1.2	0	76.4	41.9	0	3.3

Table B. 4. Projected Land-use for the Abrams Creek watershed for 50% build-out.

Subwatersheds	Land Use						
	Commercial/ Industrial	Cropland	Forest	High Density Residential	Pasture 1	Pasture 2	Rural Residential
ABR-01	35.5	0	25.3	0	20.0	1.3	5.0
ABR-02	117.9	0	191.0	169.9	79.2	62.9	286.1
ABR-03	0	0	72.1	123.9	70.3	9.5	113.4
ABR-04	25.8	0	52.6	137.8	33.3	16.9	26.4
ABR-05	0	0	21.5	122.1	21.6	1.2	6.2
ABR-06	308.2	0	80.8	352.5	18.6	12.7	252.6
ABR-07	195.6	0	179.7	776.1	71.8	30.6	392.8
ABR-08	495.2	0	51.7	415.2	8.0	0	221.8
ABR-09	847.8	19.8	175.2	503.5	147.1	9.5	423.8
ABR-10	347.1	381.9	676.8	207.3	765.7	99.6	221.6
ABR-11	269.4	276.5	234.1	524.7	308.2	2.4	129.9

Table B. 5. Projected Land-use for the Upper Opequon watershed for 50% build-out.

Subwatersheds	Land Use									
	Commercial/ Industrial	Cropland	Farmstead	Forest	High Density Residential	Loafing Lot	Pasture 1	Pasture 2	Pasture 3	Rural Residential
B08-01	17.8	0	0	9.2	0	0	17.6	0.2	0	0
B08-02	80.1	23.2	0.4	184.7	0	0	286.7	19.3	0	7.4
B08-03	25.2	12.1	0.5	191.6	0	0	89.5	50.2	1	544.2
B08-04	0	0	0.4	69.9	0	0	51.8	7.4	0	39.2
B08-05	8.4	47.9	7.6	368	0	0	966.1	130.3	15.1	15.2
B08-06	20.1	2.3	7.1	367.8	0	0	345.9	35.5	7.4	446.5
B08-07	462.9	0.1	0.3	640.7	4.4	0	341	87.1	0	794.9
B08-08	72.2	76.5	6	670.3	0	0	594.5	336.6	9.9	6
B08-09	612.7	167.9	6.5	901.8	86.8	0	763.2	23.9	6.9	879.8
B08-10	35.4	348.1	17.5	877	0	2.7	1442.9	359.2	3.5	55.5
B08-11	24.4	22.4	2.4	490.5	0	0	911.2	84.2	7.2	58
B08-12	322.9	122.4	29.2	892.4	144	0	1568.8	282.7	0	757.8
B08-13	1031.9	293.1	16.9	938.7	75.3	0	1227.1	140.7	6.9	804.1
B08-14	125.9	0	2.4	269.1	74.9	0	210.3	35.5	0	933.2
B08-15	82.4	518	26.8	1596.5	0	0	1889.3	265.8	8.6	287.4
B08-16	128.1	232.3	17.2	1823.4	0	0	2526.2	122.3	0	258.8

Table B. 6. Projected Land-use for the Lower Opequon watershed for 50% build-out.

Subwatersheds	Land Use									
	Commercial/ Industrial	Cropland	Farmstead	Forest	High Density Residential	Loafing Lot	Pasture 1	Pasture 2	Pasture 3	Rural Residential
B09-01	341.5	278.9	16.3	1146.1	0	0	1899.3	113.8	1.7	109.5
B09-02	0	60.2	5.5	456.2	0	0	802.6	160	0	13.4
B09-03	0	307.7	18.2	1541.2	0	0	2383.7	327.6	11.3	9.3
B09-04	0.7	313.2	20	192	0	0	921.2	23.4	0	0.9
B09-05	124	129	6.6	556.4	0	0	705.2	30	0	58.3
B09-06	938.7	233.4	23.1	1261.2	0	0.7	2285.9	204.2	72.5	331.6
B09-07	175.7	32.2	3.7	567.2	0	0	1110.9	23.5	0	60.1
B09-08	664.5	20.9	6.4	982.9	0	0	1643.3	54.5	0.1	257.1
B09-09	29.7	303.3	18.3	1132.2	4.3	0	1325.6	66.5	0	559.2
B09-10	0	0	5.1	671.9	0	0	530.5	78	0	222.6
B09-11	71.1	438.7	30.3	1599.2	0	0	3854.6	598.1	30.1	166.6
B09-12	6	0	0	45.7	0	0	44.4	31.2	0	5.5
B09-13	1287.8	29	4.3	911.5	83.5	0	733.6	161.6	15.7	1281.5
B09-14	2.5	0	0	47.7	2.5	0	73.7	41.9	0	4.5

Table B. 7. Projected Land-use for the Abrams Creek watershed for 100% build-out.

Subwatersheds	Land Use						
	Commercial/ Industrial	Cropland	Forest	High Density Residential	Pasture 1	Pasture 2	Rural Residential
ABR-01	62.2	0	8.4	0	6.5	1.3	8.8
ABR-02	166.8	0	66.6	240.8	19.5	9.1	404.3
ABR-03	0	0	0	203.2	0	0	186.0
ABR-04	39.8	0	0	212.4	0	0	40.7
ABR-05	0	0	0	164.3	0	0	8.3
ABR-06	346.0	0	0	395.8	0	0	283.6
ABR-07	236.1	0	0	936.5	0	0	474.0
ABR-08	521.2	0	0	437.1	0	0	233.5
ABR-09	944.6	13.8	26.6	561.2	109.0	0	471.7
ABR-10	587.5	319.3	596.0	241.7	619.8	72.1	263.7
ABR-11	361.9	258.7	97.6	704.6	146.9	2.4	173.1

Table B. 8. Projected Land-use for the Upper Opequon watershed for 100% build-out.

Subwatersheds	Land Use									
	Commercial/ Industrial	Cropland	Farmstead	Forest	High Density Residential	Loafing Lot	Pasture 1	Pasture 2	Pasture 3	Rural Residential
B08-01	24.9	0	0	8.9	0	0	10.8	0.2	0	0
B08-02	143.9	23.2	0	167.2	0	0	236.8	19.3	0	11.3
B08-03	40.4	0	0	0	0	0	0	0	0	873.8
B08-04	0	0	0	53.7	0	0	35.9	3.7	0	75.4
B08-05	8.4	47.9	7.6	368	0	0	966.1	130.3	15.1	15.2
B08-06	31.4	0.1	4.7	226.1	0	0	166.9	19.3	5.9	778.2
B08-07	669	0	0	363.5	6.4	0	107.5	26.1	0	1158.9
B08-08	72.2	76.5	6	670.3	0	0	594.5	336.6	9.9	6
B08-09	838.4	117	4.2	656.4	121.6	0	480.2	19.2	0	1212.7
B08-10	35.4	348.1	17.5	877	0	2.7	1442.9	359.2	3.5	55.5
B08-11	24.4	22.4	2.4	483.6	0	0	894.4	81.4	7.2	84.5
B08-12	573.6	118.2	27.6	709	197.5	0	1256	223.7	0	1014.4
B08-13	1635.7	255.8	13.3	504	120.5	0	746.5	8.6	6.9	1243.5
B08-14	177.7	0	0	2.4	108.2	0	20.6	0.2	0	1342.2
B08-15	137.8	513.2	26.8	1582.6	0	0	1839.9	240.2	8.6	325.6
B08-16	128.1	232.3	17.2	1823.4	0	0	2526.2	122.3	0	258.8

Table B. 9. Projected Land-use for the Lower Opequon watershed for 100% build-out.

Subwatersheds	Land Use						
	Commercial/ Industrial	Cropland	Farmstead	Forest	High Density Residential	Pasture 1	Pasture 2
B09-01	646.1	258.4	12.6	1074.3	0	1696.5	107.9
B09-02	0	60.2	5.5	456.2	0	802.6	160
B09-03	0	307.7	18.2	1541.2	0	2383.7	327.6
B09-04	0.7	313.2	20	192	0	921.2	23.4
B09-05	231.1	111	5.8	542.7	0	631.5	29.2
B09-06	1489.7	182.8	23.1	1188.9	0	1874.9	187.1
B09-07	345	32.2	2.3	532.6	0	979.4	21.7
B09-08	1168.8	0	5.9	834.6	0	1208.1	9.7
B09-09	53.8	284.5	17.5	998	4.3	1206.9	54.6
B09-10	0	0	5.1	671.9	0	530.5	78
B09-11	71.1	438.7	30.3	1599.2	0	3854.6	598.1
B09-12	6	0	0	45.7	0	44.4	31.2
B09-13	1877.4	0	1	360.5	120.3	183.3	91
B09-14	4.9	0	0	45.7	4.9	68.3	41.9

Appendix C
Sample Calculation of Cattle
(Lower Opequon Creek Sub-Watershed B09-06)

Sample Calculation: Distribution of Cattle

(Lower Opequon Sub watershed B09-06 during January)

(Note: Due to rounding, the numbers may not add up.)

Breakdown of the 550 head dairy herd is 250 milk cows, 25 dry cows, and 275 heifers.

1. During January, milk cows are confined 75% of the time (Table 4.26). Dry cows and heifers are confined 40% of the time.

Milk cows in confinement	=	250 * (75%)	=	187.5
Dry cows in confinement	=	25 * (40%)	=	10
Heifers in confinement	=	275 * (40%)	=	110

2. When not confined, dairy cows are on the pasture or in the stream.

Milk cows on pasture and in the stream =	(250 – 187.5)	=	62.5
Dry cows on pasture and in the stream	(25 – 10)	=	15
Heifers on pasture and in the stream	(275 – 110)	=	165

3. Five percent of the cows on pasture have stream access (for this example, dairy cows are assumed to graze only on Pasture 1). Hence dairy cattle with stream access are calculated as:

Milk cows on pastures with stream access	=	62.5 * (5%)	=	3.1
Dry cows on pastures with stream access	=	15 * (5%)	=	0.75
Heifers on pastures with stream access	=	165 * (5%)	=	8.3

4. Dairy cattle in and around the stream are calculated using the numbers in Step 3 and the number of hours cattle spend in the stream in January (Table 4.26) as:

Milk cows in and around streams	=	3.1 * (0.5/24)	=	0.06
Dry cows in and around streams	=	0.75 * (0.5/24)	=	0.02
Heifers in and around streams	=	8.3 * (0.5/24)	=	0.17

5. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 10% (Section 4.3.2a).

Milk cows defecating in streams	=	0.06 * (10%)	=	0.006
Dry cows defecating in streams	=	0.02 * (10%)	=	0.002
Heifers defecating in streams	=	0.17 * (10%)	=	0.017

6. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pasture is calculated by subtracting the number of cattle defecating in the stream (Step 5) from number of cattle in pasture and stream (Step 2).

Milk cows defecating on pasture	=	(62.5 – 0.006)	=	62.494
Dry cows defecating on pasture	=	(15 – 0.002)	=	14.998
Heifers defecating on pasture	=	(165 – 0.017)	=	164.983

Appendix D
Die-off Fecal Coliform During Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in dairy manure applied to cropland and pasture. All calculations were performed on spreadsheet for each sub watershed with dairy operations in a watershed.

1. It was determined from the producer survey that 15% of the dairy farms had dairy manure storage for less than 30 days; 10% of the dairy farms had storage capacities of 60 days, while the remaining operations had 180-day storage capacity. Using a decay rate of 0.375 (Section 5.5.2) for liquid dairy manure, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [5.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all dairy manure.

2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of storage period was estimated to be 0.0078 in dairy manure.

3. The annual production of fecal coliform based on 'as-excreted' values (Table 4.22) was calculated for dairy manure.

The annual fecal coliform production from dairy manure was multiplied by the fraction of surviving fecal coliform to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of dairy applied during that month based on the application schedule given in Table 4.28.

Appendix E

Weather Data Preparation

A weather data file for providing the weather data inputs into the HSPF Model was created for the period January 1980 through December 2001 using the WDMUtil. Raw data required for creating the weather data file included hourly precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi./h), and percent sun. The primary data source was Washington Reagan National Airport in Washington D.C, Virginia; data from three other NCDC stations were also used. Locations and data periods from the stations used are listed in Table E-1. Daily solar radiation data was generated using WDMUtil. The raw data required varying amounts of preprocessing prior to input into WDMUtil or within WDMUtil to obtain the following hourly values: precipitation (PREC), air temperature (ATEM), dew point temperature (DEWP), solar radiation (SOLR), wind speed (WIND), potential evapotranspiration (PEVT), potential evaporation (EVAP), and cloud cover (CLOU). The final WDM file contained the above hourly values as well as the raw data. Weather data in the variable length format were obtained from the NCDC's weather stations in Washington Reagan National Airport, VA (38°52'N Lat./ 77°02'W Long., 9.8 elevation ft); Winchester, VA (39°11'N Lat./ 78°09'W Long., 720 elevation ft); Winchester, VA (39°11'N Lat./ 78°07'W Long., 679.9 elevation ft); and Front Royal (38°54'N Lat./ 78°11'W Long., 929.9 elevation ft). While deciding on the period of record for the weather WDM file, availability of flow and water quality data was considered in addition to the availability and quality of weather data. Given these considerations, the weather WDM file was prepared for the period of January 1980 through December 2001.

Table E-1. Meteorological data sources.

Type of Data	Location	Source	Recording Frequency	Period of Record for Station	Period of Record for Data Type	Latitude Longitude
Percent of Possible Sun	Washington Reagan National Airport	NCDC	1 Day	7/1/29 – Present	1/1965 – 1/1998 -	35°52' N 77°02' W
Hourly Rainfall (in)	Front Royal	NCDC	1 Hour	2/1/1964 - Present	1979 - 1989	38°54' N 78°11' W
Daily Rainfall (in)	Winchester	NCDC	1 Day	5/1/1982 - Present	1982-2002	39°11'N 78°09'W
Daily Rainfall (in)	Winchester	NCDC	1 Day	4/1/1979 - Present	1949 - 2002	39°11'N 78°07'W
Min Air Temp (°F)	Winchester	NCDC	1 Day	4/1/1979 – Present	1949 – 2002	39°11' N 78°07'W
Max Air Temp (°F)	Winchester	NCDC	1 Day	4/1/1979 – Present	1949 – 2002	39°11' N 78°07'W
Dew Point Temp (°F)	Washington Reagan National Airport	NCDC	1 Day	7/1/29 – Present	7/1941 – 3/2003	35°52' N 77°02' W
Wind Speed (mph)	Washington Reagan National Airport	NCDC	1 Day	7/1/29 – Present	1/1984 – 3/2003	35°52' N 77°02' W

Appendix F

Fecal Coliform Loading in Sub Watersheds

Table F. 1. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed ABR-01 of the Abrams Creek watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	506,547	5,172	30,021	455	419
Feb.	461,612	4,713	27,358	414	381
Mar.	506,495	5,172	10,871	314	419
Apr.	490,106	5,004	10,520	355	405
May	506,338	5,170	10,871	472	419
Jun.	489,601	4,999	10,520	865	405
Jul.	505,921	5,166	10,871	894	419
Aug.	505,921	5,166	10,871	894	419
Sep.	490,005	5,003	29,053	644	405
Oct.	506,443	5,171	30,021	560	419
Nov.	490,157	5,005	29,053	491	405
Dec.	506,547	5,172	30,021	455	419
Total	5,965,693	60,913	240,052	6,815	4,931

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 2. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed ABR-02 of the Abrams Creek watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	1,337	1,094	191,095	2,132	82,445
Feb.	1,219	997	174,143	1,943	75,131
Mar.	1,337	1,094	72,018	929	82,445
Apr.	1,294	1,059	69,695	899	79,785
May	1,337	1,094	72,018	929	82,445
Jun.	1,294	1,059	69,695	899	79,785
Jul.	1,337	1,094	72,018	929	82,445
Aug.	1,337	1,094	72,018	929	82,445
Sep.	1,294	1,059	184,931	2,063	79,785
Oct.	1,337	1,094	191,095	2,132	82,445
Nov.	1,294	1,059	184,931	2,063	79,785
Dec.	1,337	1,094	191,095	2,132	82,445
Total	15,758	12,893	1,544,755	17,980	971,382

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 3. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed ABR-03 of the Abrams Creek watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	1,103	136	90,340	1,011	25,668
Feb.	1,005	124	82,326	921	23,391
Mar.	1,103	136	33,134	433	25,668
Apr.	1,068	132	32,065	419	24,840
May	1,103	136	33,134	433	25,668
Jun.	1,068	132	32,065	419	24,840
Jul.	1,103	136	33,134	433	25,668
Aug.	1,103	136	33,134	433	25,668
Sep.	1,068	132	87,426	978	24,840
Oct.	1,103	136	90,340	1,011	25,668
Nov.	1,068	132	87,426	978	24,840
Dec.	1,103	136	90,340	1,011	25,668
Total	12,998	1,606	724,869	8,477	302,427

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 4. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed ABR-04 of the Abrams Creek watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	644	362	90,165	1,026	58,311
Feb.	587	330	82,167	935	53,138
Mar.	644	362	32,959	448	58,311
Apr.	623	351	31,896	433	56,430
May	644	362	32,959	448	58,311
Jun.	623	351	31,896	433	56,430
Jul.	644	362	32,959	448	58,311
Aug.	644	362	32,959	448	58,311
Sep.	623	351	87,257	993	56,430
Oct.	644	362	90,165	1,026	58,311
Nov.	623	351	87,257	993	56,430
Dec.	644	362	90,165	1,026	58,311
Total	7,590	4,269	722,804	8,655	687,035

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 5. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds ABR-05 of the Abrams Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	533	34	50,124	558	44,919
Feb.	486	31	45,677	508	40,934
Mar.	533	34	16,488	218	44,919
Apr.	516	33	15,956	211	43,470
May	533	34	16,488	218	44,919
Jun.	516	33	15,956	211	43,470
Jul.	533	34	16,488	218	44,919
Aug.	533	34	16,488	218	44,919
Sep.	516	33	48,507	540	43,470
Oct.	533	34	50,124	558	44,919
Nov.	516	33	48,507	540	43,470
Dec.	533	34	50,124	558	44,919
Total	6,282	401	390,925	4,553	529,247

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 6. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds ABR-06 of the Abrams Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	973	705	122,732	1,361	301,041
Feb.	887	642	111,844	1,240	274,336
Mar.	973	705	46,621	592	301,041
Apr.	942	682	45,117	573	291,330
May	973	705	46,621	592	301,041
Jun.	942	682	45,117	573	291,330
Jul.	973	705	46,621	592	301,041
Aug.	973	705	46,621	592	301,041
Sep.	942	682	118,773	1,317	291,330
Oct.	973	705	122,732	1,361	301,041
Nov.	942	682	118,773	1,317	291,330
Dec.	973	705	122,732	1,361	301,041
Total	11,467	8,304	994,303	11,467	3,546,943

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 7. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds ABR-07 of the Abrams Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	2,576	1,052	194,042	2,204	389,205
Feb.	2,348	959	176,829	2,008	354,679
Mar.	2,576	1,052	74,965	1,001	389,205
Apr.	2,493	1,018	72,547	969	376,650
May	2,576	1,052	74,965	1,001	389,205
Jun.	2,493	1,018	72,547	969	376,650
Jul.	2,576	1,052	74,965	1,001	389,205
Aug.	2,576	1,052	74,965	1,001	389,205
Sep.	2,493	1,018	187,783	2,133	376,650
Oct.	2,576	1,052	194,042	2,204	389,205
Nov.	2,493	1,018	187,783	2,133	376,650
Dec.	2,576	1,052	194,042	2,204	389,205
Total	30,357	12,399	1,579,476	18,827	4,585,714

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 8. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds ABR-08 of the Abrams Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)			
	Pasture 1	Forest	Stream	Residential[1]
Jan.	874	94,210	998	507,362
Feb.	796	85,853	909	462,354
Mar.	874	37,250	423	507,362
Apr.	846	36,048	409	490,995
May	874	37,250	423	507,362
Jun.	846	36,048	409	490,995
Jul.	874	37,250	423	507,362
Aug.	874	37,250	423	507,362
Sep.	846	91,171	966	490,995
Oct.	874	94,210	998	507,362
Nov.	846	91,171	966	490,995
Dec.	874	94,210	998	507,362
Total	10,297	771,922	8,344	5,977,864

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 9. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed ABR-09 of the Abrams Creek watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	471	3,743	370	175,007	1,888	453,096
Feb.	430	3,411	337	159,482	1,720	412,902
Mar.	471	3,743	370	65,259	779	453,096
Apr.	456	3,622	358	63,154	754	438,480
May	471	3,743	370	65,259	779	453,096
Jun.	456	3,622	358	63,154	754	438,480
Jul.	471	3,743	370	65,259	779	453,096
Aug.	471	3,743	370	65,259	779	453,096
Sep.	456	3,622	358	169,361	1,827	438,480
Oct.	471	3,743	370	175,007	1,888	453,096
Nov.	456	3,622	358	169,361	1,827	438,480
Dec.	471	3,743	370	175,007	1,888	453,096
Total	5,553	44,099	4,361	1,410,568	15,663	5,338,494

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 10. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed ABR-10 of the Abrams Creek watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Loafing Lot	Forest	Stream	Residential[1]
Jan.	2,949	1,203,776	82,487	1,696,850	183,568	2,752	114,725
Feb.	2,687	1,096,989	75,169	1,546,323	167,284	2,508	104,548
Mar.	2,949	1,203,464	82,465	1,696,850	69,401	1,933	114,725
Apr.	2,854	1,824,690	124,808	2,578,117	67,162	2,928	111,024
May	2,949	1,202,527	82,401	1,696,850	69,401	2,933	114,725
Jun.	2,854	1,161,320	79,579	1,642,113	67,162	5,419	111,024
Jul.	2,949	1,200,031	82,231	1,696,850	69,401	5,599	114,725
Aug.	2,949	1,200,031	82,231	1,696,850	69,401	5,599	114,725
Sep.	2,854	1,823,741	124,744	2,578,117	177,646	5,057	111,024
Oct.	2,949	1,885,513	128,969	2,664,055	183,568	4,179	114,725
Nov.	2,854	1,164,642	79,805	1,642,113	177,646	2,986	111,024
Dec.	2,949	1,203,776	82,487	1,696,850	183,568	2,752	114,725
Total	34,745	16,170,499	1,107,376	22,831,939	1,485,210	44,648	1,351,717

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 11. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed ABR-11 of the Abrams Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Cropland	Pasture 1	Forest	Stream	Residential[1]
Jan.	2,163	514,937	131,849	1,725	120,692
Feb.	1,971	469,257	120,152	1,572	109,986
Mar.	2,163	514,804	51,073	1,042	120,692
Apr.	2,094	498,068	49,425	1,138	116,799
May	2,163	514,404	51,073	1,442	120,692
Jun.	2,094	496,779	49,425	2,427	116,799
Jul.	2,163	513,338	51,073	2,508	120,692
Aug.	2,163	513,338	51,073	2,508	120,692
Sep.	2,094	497,810	127,595	2,185	116,799
Oct.	2,163	514,670	131,849	1,992	120,692
Nov.	2,094	498,197	127,595	1,798	116,799
Dec.	2,163	514,937	131,849	1,725	120,692
Total	25,490	6,060,539	1,074,030	22,062	1,422,028

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 12. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-01 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	222	2	2,052	48	2,440
Feb.	203	2	1,870	44	2,223
Mar.	222	2	1,315	41	2,440
Apr.	215	2	1,273	40	2,361
May	222	2	1,315	41	2,440
Jun.	215	2	1,273	40	2,361
Jul.	222	2	1,315	41	2,440
Aug.	222	2	1,315	41	2,440
Sep.	215	2	1,986	47	2,361
Oct.	222	2	2,052	48	2,440
Nov.	215	2	1,986	47	2,361
Dec.	222	2	2,052	48	2,440
Total	2,621	26	19,804	526	28,745

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 13. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-02 of the Upper Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	147	2,139	113	8,421	234	8,674
Feb.	134	1,949	103	7,674	213	7,904
Mar.	147	2,139	113	5,475	205	5,698
Apr.	142	2,070	109	5,298	198	5,514
May	147	2,139	113	5,475	205	5,698
Jun.	142	2,070	109	5,298	198	5,514
Jul.	147	2,139	113	5,475	205	5,698
Aug.	147	2,139	113	5,475	205	5,698
Sep.	142	2,070	109	8,150	227	8,394
Oct.	147	2,139	113	8,421	234	8,674
Nov.	142	2,070	109	8,150	227	8,394
Dec.	147	2,139	113	8,421	234	8,674
Total	1,730	25,205	1,327	81,733	2,583	84,534

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 14. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-03 of the Upper Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	216	1,609	905	22,537	493	79,655
Feb.	197	1,467	825	20,538	450	72,588
Mar.	216	1,609	905	16,645	434	79,655
Apr.	209	1,557	876	16,108	420	77,085
May	216	1,609	905	16,645	434	79,655
Jun.	209	1,557	876	16,108	420	77,085
Jul.	216	1,609	905	16,645	434	79,655
Aug.	216	1,609	905	16,645	434	79,655
Sep.	209	1,557	876	21,810	478	77,085
Oct.	216	1,609	905	22,537	493	79,655
Nov.	209	1,557	876	21,810	478	77,085
Dec.	216	1,609	905	22,537	493	79,655
Total	2,548	18,961	10,666	230,565	5,461	938,510

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 15. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-04 of the Upper Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	622	101	5,774	172	2,651
Feb.	567	92	5,261	157	2,415
Mar.	622	101	4,546	159	2,651
Apr.	602	98	4,399	154	2,565
May	622	101	4,546	159	2,651
Jun.	602	98	4,399	154	2,565
Jul.	622	101	4,546	159	2,651
Aug.	622	101	4,546	159	2,651
Sep.	602	98	5,587	166	2,565
Oct.	622	101	5,774	172	2,651
Nov.	602	98	5,587	166	2,565
Dec.	622	101	5,774	172	2,651
Total	7,326	1,193	60,740	1,951	31,229

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 16. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-05 of the Upper Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Stream	Residential[1]
Jan.	272	5,497	758	63	30,105	534	36,177
Feb.	248	5,010	691	58	27,434	487	32,968
Mar.	272	5,497	758	63	21,266	445	36,177
Apr.	264	5,320	734	61	20,580	431	35,010
May	272	5,497	758	63	21,266	445	36,177
Jun.	264	5,320	734	61	20,580	431	35,010
Jul.	272	5,497	758	63	21,266	445	36,177
Aug.	272	5,497	758	63	21,266	445	36,177
Sep.	264	5,320	734	61	29,133	517	35,010
Oct.	272	5,497	758	63	30,105	534	36,177
Nov.	264	5,320	734	61	29,133	517	35,010
Dec.	272	5,497	758	63	30,105	534	36,177
Total	3,208	64,769	8,934	744	302,238	5,765	426,247

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 17. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-06 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Stream	Residential[1]
Jan.	32	137,809	7,076	414	31,432	634	50,294
Feb.	29	146,837	7,511	436	28,644	578	45,833
Mar.	32	273,849	13,878	792	22,593	545	50,294
Apr.	31	272,538	13,807	787	21,865	528	48,672
May	32	289,397	14,655	835	22,593	545	50,294
Jun.	31	287,584	14,559	829	21,865	528	48,672
Jul.	32	304,944	15,433	878	22,593	545	50,294
Aug.	32	312,718	15,822	900	22,593	545	50,294
Sep.	31	310,153	15,687	891	30,418	614	48,672
Oct.	32	198,056	10,088	581	31,432	634	50,294
Nov.	31	201,070	10,233	588	30,418	614	48,672
Dec.	32	131,979	6,785	398	31,432	634	50,294
Total	373	2,866,935	145,534	8,328	317,879	6,945	592,582

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 18. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-07 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	1	4,790	1,273	26,005	610	86,168
Feb.	1	4,365	1,160	23,698	556	78,524
Mar.	1	4,790	1,273	20,112	550	86,168
Apr.	1	4,635	1,232	19,464	532	83,388
May	1	4,790	1,273	20,112	550	86,168
Jun.	1	4,635	1,232	19,464	532	83,388
Jul.	1	4,790	1,273	20,112	550	86,168
Aug.	1	4,790	1,273	20,112	550	86,168
Sep.	1	4,635	1,232	25,166	590	83,388
Oct.	1	4,790	1,273	26,005	610	86,168
Nov.	1	4,635	1,232	25,166	590	83,388
Dec.	1	4,790	1,273	26,005	610	86,168
Total	10	56,433	15,001	271,422	6,829	1,015,249

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 19. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-08 of the Upper Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Stream	Residential[1]
Jan.	479	3,708	2,119	59	26,787	632	24,165
Feb.	436	3,379	1,931	54	24,411	576	22,021
Mar.	479	3,708	2,119	59	19,176	555	24,165
Apr.	463	3,589	2,051	57	18,558	538	23,385
May	479	3,708	2,119	59	19,176	555	24,165
Jun.	463	3,589	2,051	57	18,558	538	23,385
Jul.	479	3,708	2,119	59	19,176	555	24,165
Aug.	479	3,708	2,119	59	19,176	555	24,165
Sep.	463	3,589	2,051	57	25,923	612	23,385
Oct.	479	3,708	2,119	59	26,787	632	24,165
Nov.	463	3,589	2,051	57	25,923	612	23,385
Dec.	479	3,708	2,119	59	26,787	632	24,165
Total	5,638	43,692	24,967	694	270,440	6,994	284,712

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 20. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-09 of the Upper Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Stream	Residential[1]
Jan.	1,790	700,338	11,076	1,891	46,773	2,539	172,004
Feb.	1,631	747,850	11,807	2,008	42,623	2,547	156,745
Mar.	1,790	1,400,698	22,019	3,714	34,988	5,393	172,004
Apr.	1,732	1,392,836	21,892	3,692	33,859	6,817	166,455
May	1,790	1,476,207	23,199	3,911	34,988	10,348	172,004
Jun.	1,732	1,455,001	22,864	3,854	33,859	22,719	166,455
Jul.	1,790	1,543,102	24,245	4,085	34,988	24,073	172,004
Aug.	1,790	1,582,703	24,863	4,188	34,988	24,670	172,004
Sep.	1,732	1,583,179	24,866	4,188	45,264	11,119	166,455
Oct.	1,790	1,009,049	15,900	2,695	46,773	5,331	172,004
Nov.	1,732	1,025,974	16,160	2,736	45,264	4,282	166,455
Dec.	1,790	670,260	10,606	1,812	46,773	2,475	172,004
Total	21,086	14,587,196	229,499	38,774	481,136	122,314	2,026,590

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 21. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-10 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)						
	Cropland	Pasture 1	Pasture 2	Loafing Lot	Forest	Stream	Residential[1]
Jan.	2,154	509,846	64,848	141,174	71,108	2,661	84,165
Feb.	1,963	544,004	69,019	151,025	64,800	2,611	76,699
Mar.	2,154	1,016,959	128,237	284,394	50,484	4,831	84,165
Apr.	2,085	1,011,177	127,479	283,140	48,856	5,954	81,450
May	2,154	1,071,633	135,072	300,762	50,484	8,795	84,165
Jun.	2,085	1,056,189	133,105	298,980	48,856	18,675	81,450
Jul.	2,154	1,120,070	141,126	317,130	50,484	19,775	84,165
Aug.	2,154	1,148,744	144,711	325,314	50,484	20,252	84,165
Sep.	2,085	1,149,000	144,706	322,740	68,814	9,505	81,450
Oct.	2,154	733,376	92,789	204,600	71,108	4,894	84,165
Nov.	2,085	745,542	94,274	207,900	68,814	4,035	81,450
Dec.	2,154	488,068	62,126	135,036	71,108	2,609	84,165
Total	25,384	10,594,608	1,337,493	2,972,195	715,403	104,596	991,654

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 22. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-11 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	139	5,765	570	20,150	601	35,957
Feb.	127	5,253	520	18,362	548	32,767
Mar.	139	5,765	570	14,994	549	35,957
Apr.	134	5,579	552	14,510	531	34,797
May	139	5,765	570	14,994	549	35,957
Jun.	134	5,579	552	14,510	531	34,797
Jul.	139	5,765	570	14,994	549	35,957
Aug.	139	5,765	570	14,994	549	35,957
Sep.	134	5,579	552	19,500	582	34,797
Oct.	139	5,765	570	20,150	601	35,957
Nov.	134	5,579	552	19,500	582	34,797
Dec.	139	5,765	570	20,150	601	35,957
Total	1,636	67,920	6,717	206,809	6,775	423,653

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 23. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-12 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	875	13,065	2,306	62,922	1,398	396,217
Feb.	797	11,906	2,101	57,341	1,274	361,069
Mar.	875	13,065	2,306	45,245	1,220	396,217
Apr.	846	12,643	2,231	43,785	1,180	383,436
May	875	13,065	2,306	45,245	1,220	396,217
Jun.	846	12,643	2,231	43,785	1,180	383,436
Jul.	875	13,065	2,306	45,245	1,220	396,217
Aug.	875	13,065	2,306	45,245	1,220	396,217
Sep.	846	12,643	2,231	60,893	1,353	383,436
Oct.	875	13,065	2,306	62,922	1,398	396,217
Nov.	846	12,643	2,231	60,893	1,353	383,436
Dec.	875	13,065	2,306	62,922	1,398	396,217
Total	10,304	153,933	27,165	636,443	15,416	4,668,333

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 24. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-13 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	2,349	12,146	1,977	78,139	1,595	227,959
Feb.	2,140	11,068	1,802	71,208	1,454	207,736
Mar.	2,349	12,146	1,977	56,534	1,377	227,959
Apr.	2,273	11,754	1,913	54,710	1,333	220,605
May	2,349	12,146	1,977	56,534	1,377	227,959
Jun.	2,273	11,754	1,913	54,710	1,333	220,605
Jul.	2,349	12,146	1,977	56,534	1,377	227,959
Aug.	2,349	12,146	1,977	56,534	1,377	227,959
Sep.	2,273	11,754	1,913	75,619	1,544	220,605
Oct.	2,349	12,146	1,977	78,139	1,595	227,959
Nov.	2,273	11,754	1,913	75,619	1,544	220,605
Dec.	2,349	12,146	1,977	78,139	1,595	227,959
Total	27,671	143,106	23,296	792,419	17,500	2,685,866

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 25. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-14 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	389	687	34,974	637	214,477
Feb.	355	626	31,872	580	195,450
Mar.	389	687	25,154	538	214,477
Apr.	377	665	24,342	520	207,558
May	389	687	25,154	538	214,477
Jun.	377	665	24,342	520	207,558
Jul.	389	687	25,154	538	214,477
Aug.	389	687	25,154	538	214,477
Sep.	377	665	33,846	616	207,558
Oct.	389	687	34,974	637	214,477
Nov.	377	665	33,846	616	207,558
Dec.	389	687	34,974	637	214,477
Total	4,589	8,098	353,787	6,915	2,527,019

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 26. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-15 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	3,014	2,959,870	221,979	42,603	7,352	149,547
Feb.	2,747	2,998,437	224,786	38,824	7,375	136,281
Mar.	3,014	5,597,640	419,054	31,801	19,448	149,547
Apr.	2,917	4,347,676	325,638	30,775	20,108	144,723
May	3,014	4,525,412	338,945	31,801	31,139	149,547
Jun.	2,917	4,423,768	331,323	30,775	70,793	144,723
Jul.	3,014	4,654,897	348,619	31,801	74,484	149,547
Aug.	3,014	4,696,732	351,744	31,801	75,149	149,547
Sep.	2,917	4,134,465	309,709	41,229	28,584	144,723
Oct.	3,014	4,238,937	317,541	42,603	19,747	149,547
Nov.	2,917	4,311,257	322,917	41,229	15,200	144,723
Dec.	3,014	2,832,773	212,483	42,603	7,067	149,547
Total	35,514	49,721,864	3,724,738	437,844	376,446	1,762,003

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 27. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B08-16 of the Upper Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	1,422	2,742,596	72,566	63,727	6,932	147,284
Feb.	1,295	2,863,587	75,715	58,073	7,097	134,219
Mar.	1,422	5,378,457	141,931	47,031	18,175	147,284
Apr.	1,376	5,388,772	142,190	45,514	23,968	142,533
May	1,422	4,815,262	127,110	47,031	31,904	147,284
Jun.	1,376	4,733,330	124,941	45,514	72,563	142,533
Jul.	1,422	5,007,207	132,161	47,031	76,745	147,284
Aug.	1,422	5,162,007	136,235	47,031	79,096	147,284
Sep.	1,376	3,829,028	101,144	61,671	25,675	142,533
Oct.	1,422	3,925,817	103,703	63,727	17,882	147,284
Nov.	1,376	3,992,572	105,447	61,671	13,851	142,533
Dec.	1,422	2,601,508	68,853	63,727	6,629	147,284
Total	16,750	50,440,143	1,331,995	651,748	380,516	1,735,339

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 28. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-01 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	1,860	2,179,195	57,693	67,789	2,587	89,810
Feb.	1,695	1,999,500	52,933	61,775	2,362	81,843
Mar.	1,860	3,426,465	90,516	48,588	2,690	89,810
Apr.	1,800	3,461,759	91,433	47,021	2,940	86,913
May	1,860	3,576,520	94,464	48,588	3,686	89,810
Jun.	1,800	3,458,706	91,353	47,021	6,074	86,913
Jul.	1,860	3,573,997	94,398	48,588	6,276	89,810
Aug.	1,860	3,573,997	94,398	48,588	6,276	89,810
Sep.	1,800	3,822,540	100,928	65,602	4,294	86,913
Oct.	1,860	3,975,610	104,967	67,789	3,686	89,810
Nov.	1,800	3,725,703	98,379	65,602	3,180	86,913
Dec.	1,860	2,164,248	57,299	67,789	2,582	89,810
Total	21,919	38,938,240	1,028,761	684,741	46,634	1,058,166

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 29. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-02 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	335	4,452	912	26,314	683	27,261
Feb.	305	4,057	831	23,979	623	24,843
Mar.	335	4,452	912	18,536	525	27,261
Apr.	324	4,308	882	17,938	508	26,382
May	335	4,452	912	18,536	525	27,261
Jun.	324	4,308	882	17,938	508	26,382
Jul.	335	4,452	912	18,536	525	27,261
Aug.	335	4,452	912	18,536	525	27,261
Sep.	324	4,308	882	25,465	661	26,382
Oct.	335	4,452	912	26,314	683	27,261
Nov.	324	4,308	882	25,465	661	26,382
Dec.	335	4,452	912	26,314	683	27,261
Total	3,949	52,454	10,744	263,873	7,108	321,201

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 30. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-03 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	1,679	13,075	1,783	38,407	1,040	71,244
Feb.	1,530	11,915	1,625	35,000	947	64,924
Mar.	1,679	13,075	1,783	29,657	861	71,244
Apr.	1,625	12,653	1,725	28,701	833	68,946
May	1,679	13,075	1,783	29,657	861	71,244
Jun.	1,625	12,653	1,725	28,701	833	68,946
Jul.	1,679	13,075	1,783	29,657	861	71,244
Aug.	1,679	13,075	1,783	29,657	861	71,244
Sep.	1,625	12,653	1,725	37,168	1,006	68,946
Oct.	1,679	13,075	1,783	38,407	1,040	71,244
Nov.	1,625	12,653	1,725	37,168	1,006	68,946
Dec.	1,679	13,075	1,783	38,407	1,040	71,244
Total	19,785	154,055	21,008	400,588	11,189	839,418

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 31. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-04 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	1,725	3,858,494	39,424	21,611	1,359	21,483
Feb.	1,572	3,751,457	38,328	19,694	1,313	19,577
Mar.	1,725	7,554,458	77,138	15,049	2,715	21,483
Apr.	1,670	7,724,942	78,876	14,564	3,476	20,790
May	1,725	8,056,765	82,264	15,049	5,233	21,483
Jun.	1,670	7,839,655	80,047	14,564	11,342	20,790
Jul.	1,725	8,176,761	83,488	15,049	11,888	21,483
Aug.	1,725	8,252,544	84,262	15,049	12,056	21,483
Sep.	1,670	8,066,116	82,358	20,914	5,449	20,790
Oct.	1,725	7,046,309	71,953	21,611	3,134	21,483
Nov.	1,670	6,600,599	67,403	20,914	2,421	20,790
Dec.	1,725	3,782,568	38,650	21,611	1,335	21,483
Total	20,328	80,710,669	824,191	215,683	61,720	253,118

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 32. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-05 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	955	5,054	211	34,300	1,065	57,862
Feb.	871	4,606	192	31,257	971	52,729
Mar.	955	5,054	211	24,578	867	57,862
Apr.	925	4,891	204	23,785	839	55,995
May	955	5,054	211	24,578	867	57,862
Jun.	925	4,891	204	23,785	839	55,995
Jul.	955	5,054	211	24,578	867	57,862
Aug.	955	5,054	211	24,578	867	57,862
Sep.	925	4,891	204	33,193	1,031	55,995
Oct.	955	5,054	211	34,300	1,065	57,862
Nov.	925	4,891	204	33,193	1,031	55,995
Dec.	955	5,054	211	34,300	1,065	57,862
Total	11,257	59,553	2,481	346,426	11,370	681,739

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 33. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-06 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)							
	Cropland	Pasture 1	Pasture 2	Pasture 3	Loafing Lot	Forest	Stream	Residential[1]
Jan.	1,812	2,340,050	91,670	13,286	431,457	54,847	2,118	110,050
Feb.	1,651	2,335,481	91,433	13,236	446,209	49,982	1,996	100,288
Mar.	1,812	4,605,733	179,780	25,874	906,514	40,265	2,880	110,050
Apr.	1,754	4,672,098	182,339	26,233	933,542	38,966	3,379	106,500
May	1,812	4,900,993	191,262	27,514	984,056	40,265	4,666	110,050
Jun.	1,754	4,810,454	187,719	27,002	971,083	38,966	9,037	106,500
Jul.	1,812	5,044,923	196,859	28,314	1,022,848	40,265	9,508	110,050
Aug.	1,812	5,119,043	199,742	28,725	1,042,244	40,265	9,678	110,050
Sep.	1,754	5,030,174	196,264	28,222	1,027,394	53,078	5,085	106,500
Oct.	1,812	4,029,793	157,382	22,674	756,152	54,847	3,268	110,050
Nov.	1,754	3,846,411	150,229	21,646	717,723	53,078	2,776	106,500
Dec.	1,812	2,284,355	89,504	12,977	416,910	54,847	2,100	110,050
Total	21,351	49,019,506	1,914,181	275,702	9,656,132	559,671	56,492	1,296,638

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 34. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-07 of the Lower Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	205	7,908	161	36,383	1,205	80,426
Feb.	187	7,207	147	33,155	1,098	73,292
Mar.	205	7,908	161	25,689	987	80,426
Apr.	198	7,653	156	24,860	955	77,832
May	205	7,908	161	25,689	987	80,426
Jun.	198	7,653	156	24,860	955	77,832
Jul.	205	7,908	161	25,689	987	80,426
Aug.	205	7,908	161	25,689	987	80,426
Sep.	198	7,653	156	35,209	1,166	77,832
Oct.	205	7,908	161	36,383	1,205	80,426
Nov.	198	7,653	156	35,209	1,166	77,832
Dec.	205	7,908	161	36,383	1,205	80,426
Total	2,416	93,175	1,902	365,196	12,906	947,605

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 35. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-08 of the Lower Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	264	719,783	19,286	66,544	2,169	70,141
Feb.	241	688,621	18,436	60,641	1,987	63,918
Mar.	264	598,920	16,106	48,073	1,847	70,141
Apr.	256	567,944	15,279	46,522	1,871	67,878
May	264	574,746	15,469	48,073	2,106	70,141
Jun.	256	855,827	22,855	46,522	3,412	67,878
Jul.	264	920,160	24,559	48,073	3,606	70,141
Aug.	264	961,933	25,659	48,073	3,700	70,141
Sep.	256	966,746	25,774	64,397	2,798	67,878
Oct.	264	1,023,187	27,271	66,544	2,590	70,141
Nov.	256	1,042,399	27,765	64,397	2,375	67,878
Dec.	264	687,497	18,437	66,544	2,158	70,141
Total	3,113	9,607,762	256,896	674,402	30,618	826,415

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 36. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-09 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^{8} cfu/month)					
	Cropland	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	1,987	8,924	470	34,435	904	110,664
Feb.	1,811	8,132	428	31,381	823	100,847
Mar.	1,987	8,924	470	25,686	725	110,664
Apr.	1,923	8,636	455	24,857	702	107,094
May	1,987	8,924	470	25,686	725	110,664
Jun.	1,923	8,636	455	24,857	702	107,094
Jul.	1,987	8,924	470	25,686	725	110,664
Aug.	1,987	8,924	470	25,686	725	110,664
Sep.	1,923	8,636	455	33,324	874	107,094
Oct.	1,987	8,924	470	34,435	904	110,664
Nov.	1,923	8,636	455	33,324	874	107,094
Dec.	1,987	8,924	470	34,435	904	110,664
Total	23,416	105,142	5,534	353,793	9,587	1,303,869

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 37. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-10 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^{8} cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	4,232	632	39,518	1,230	67,518
Feb.	3,857	576	36,012	1,121	61,529
Mar.	4,232	632	28,581	1,007	67,518
Apr.	4,095	612	27,659	974	65,340
May	4,232	632	28,581	1,007	67,518
Jun.	4,095	612	27,659	974	65,340
Jul.	4,232	632	28,581	1,007	67,518
Aug.	4,232	632	28,581	1,007	67,518
Sep.	4,095	612	38,243	1,190	65,340
Oct.	4,232	632	39,518	1,230	67,518
Nov.	4,095	612	38,243	1,190	65,340
Dec.	4,232	632	39,518	1,230	67,518
Total	49,862	7,451	400,694	13,164	795,515

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 38. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-11 of the Lower Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Stream	Residential[1]
Jan.	2,524	1,330,769	102,258	4,062	84,883	2,881	185,814
Feb.	2,300	1,420,109	108,862	4,304	77,353	2,695	169,331
Mar.	2,524	2,657,912	202,565	7,920	61,308	3,292	185,814
Apr.	2,442	2,645,165	201,548	7,877	59,331	3,665	179,820
May	2,524	2,808,302	213,932	8,357	61,308	4,778	185,814
Jun.	2,442	2,787,613	212,314	8,291	59,331	8,435	179,820
Jul.	2,524	2,956,252	225,114	8,787	61,308	8,896	185,814
Aug.	2,524	3,031,970	230,837	9,007	61,308	9,075	185,814
Sep.	2,442	3,011,180	229,212	8,941	82,145	5,387	179,820
Oct.	2,524	1,918,094	146,649	5,769	84,883	3,718	185,814
Nov.	2,442	1,948,259	148,874	5,851	82,145	3,335	179,820
Dec.	2,524	1,273,874	97,958	3,897	84,883	2,862	185,814
Total	29,737	27,789,499	2,120,120	83,062	860,189	59,018	2,189,309

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 39. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-12 of the Lower Opequon watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	361	251	5,455	186	6,826
Feb.	329	228	4,971	169	6,221
Mar.	361	251	3,511	146	6,826
Apr.	349	242	3,398	141	6,606
May	361	251	3,511	146	6,826
Jun.	349	242	3,398	141	6,606
Jul.	361	251	3,511	146	6,826
Aug.	361	251	3,511	146	6,826
Sep.	349	242	5,279	180	6,606
Oct.	361	251	5,455	186	6,826
Nov.	349	242	5,279	180	6,606
Dec.	361	251	5,455	186	6,826
Total	4,248	2,952	52,734	1,953	80,428

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 40. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-13 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x 10^8 cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Stream	Residential[1]
Jan.	482	10,688	1,909	127	69,177	1,824	201,342
Feb.	439	9,740	1,739	116	63,040	1,662	183,481
Mar.	482	10,688	1,909	127	50,949	1,452	201,342
Apr.	466	10,343	1,847	123	49,305	1,405	194,847
May	482	10,688	1,909	127	50,949	1,452	201,342
Jun.	466	10,343	1,847	123	49,305	1,405	194,847
Jul.	482	10,688	1,909	127	50,949	1,452	201,342
Aug.	482	10,688	1,909	127	50,949	1,452	201,342
Sep.	466	10,343	1,847	123	66,945	1,765	194,847
Oct.	482	10,688	1,909	127	69,177	1,824	201,342
Nov.	466	10,343	1,847	123	66,945	1,765	194,847
Dec.	482	10,688	1,909	127	69,177	1,824	201,342
Total	5,676	125,931	22,488	1,499	706,866	19,285	2,372,262

[1]Includes Farmstead, Low and High Density Residential Loads

Table F. 41. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B09-14 of the Lower Opequon watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Pasture 1	Pasture 2	Forest	Stream	Residential[1]
Jan.	513	276	3,496	128	2,719
Feb.	468	252	3,186	117	2,478
Mar.	513	276	2,524	108	2,719
Apr.	497	267	2,442	105	2,631
May	513	276	2,524	108	2,719
Jun.	497	267	2,442	105	2,631
Jul.	513	276	2,524	108	2,719
Aug.	513	276	2,524	108	2,719
Sep.	497	267	3,383	124	2,631
Oct.	513	276	3,496	128	2,719
Nov.	497	267	3,383	124	2,631
Dec.	513	276	3,496	128	2,719
Total	6,046	3,256	35,417	1,391	32,032

[1]Includes Farmstead, Low and High Density Residential Loads

Appendix G
Observed Fecal Coliform Concentrations and Antecedent Rainfall

Table G. 1. Observed FC concentration and antecedent rainfall for Abrams Creek

Station	Date	cfu/100mL	Total Rainfall for sampling day and preceding 5 days (inches)
1AABR000.78	7/1/1992	1,200	0.30
1AABR000.78	8/4/1992	1,200	0.20
1AABR000.78	9/16/1992	1,500	0.00
1AABR000.78	10/21/1992	100	0.00
1AABR000.78	11/16/1992	100	0.60
1AABR000.78	12/3/1992	100	0.10
1AABR000.78	1/13/1993	100	0.80
1AABR000.78	2/3/1993	100	0.00
1AABR000.78	3/3/1993	100	0.30
1AABR000.78	4/14/1993	100	1.30
1AABR000.78	5/4/1993	600	0.10
1AABR000.78	6/10/1993	100	1.20
1AABR000.78	7/1/1993	600	0.60
1AABR000.78	8/2/1993	600	0.30
1AABR000.78	9/14/1993	500	0.00
1AABR000.78	10/4/1993	700	0.40
1AABR000.78	11/15/1993	100	0.40
1AABR000.78	1/3/1994	100	0.20
1AABR000.78	2/1/1994	100	0.60
1AABR000.78	3/1/1994	100	1.90
1AABR000.78	4/4/1994	100	0.05
1AABR000.78	5/4/1994	100	0.84
1AABR000.78	5/9/1994	700	1.85
1AABR000.78	6/13/1994	1,900	0.01
1AABR000.78	7/5/1994	1,300	0.25
1AABR000.78	8/1/1994	300	0.52
1AABR000.78	9/1/1994	1,000	0.45
1AABR000.78	10/3/1994	200	0.13
1AABR000.78	11/8/1994	100	0.02
1AABR000.78	12/1/1994	100	0.80
1AABR000.78	1/3/1995	100	0.30
1AABR000.78	2/9/1995	100	0.01
1AABR000.78	3/2/1995	100	0.12
1AABR000.78	4/3/1995	100	0.00
1AABR000.78	6/5/1995	300	1.09
1AABR000.78	7/5/1995	600	0.70
1AABR000.78	8/1/1995	500	0.00
1AABR000.78	9/5/1995	100	0.00
1AABR000.78	10/16/1995	1,100	0.79

Table G. 1. Observed FC concentration and antecedent rainfall for Abrams Creek
Continued

1AABR000.78	11/1/1995	2,300	0.32
1AABR000.78	12/20/1995	100	1.80
1AABR000.78	1/16/1996	100	0.40
1AABR000.78	2/1/1996	8,000	1.00
1AABR000.78	3/4/1996	100	0.00
1AABR000.78	4/1/1996	600	2.08
1AABR000.78	5/1/1996	500	0.97
1AABR000.78	7/1/1996	600	0.00
1AABR000.78	8/15/1996	200	3.10
1AABR000.78	9/4/1996	5,500	0.90
1AABR000.78	10/7/1996	500	0.00
1AABR000.78	11/20/1996	100	0.30
1AABR000.78	12/2/1996	600	1.30
1AABR000.78	1/2/1997	100	0.10
1AABR000.78	2/3/1997	100	0.00
1AABR000.78	3/4/1997	900	1.90
1AABR000.78	4/1/1997	100	0.60
1AABR000.78	5/19/1997	100	0.00
1AABR000.78	6/2/1997	3,300	2.50

Table G. 2. Observed FC concentration and antecedent rainfall for Upper Opequon

Station	Date	cfu/100mL	Total Rainfall for sampling day and preceding 5 days (inches)
OPEO36.13	9/16/1992	800	0.00
OPEO36.13	10/21/1992	100	0.00
OPEO36.13	11/16/1992	100	0.60
OPEO36.13	12/3/1992	100	0.10
OPEO36.13	1/13/1993	1,300	0.80
OPEO36.13	2/3/1993	100	0.00
OPEO36.13	3/3/1993	100	0.30
OPEO36.13	4/14/1993	100	1.30
OPEO36.13	5/4/1993	300	0.10
OPEO36.13	6/10/1993	400	1.20
OPEO36.13	7/1/1993	700	0.60
OPEO36.13	8/2/1993	300	0.30
OPEO36.13	9/14/1993	100	0.00
OPEO36.13	10/4/1993	300	0.40
OPEO36.13	11/15/1993	100	0.40
OPEO36.13	1/3/1994	100	0.20
OPEO36.13	2/1/1994	300	0.60

Table G. 2. Observed FC concentration and antecedent rainfall for Upper Opequon

Continued

OPEO36.13	3/1/1994	100	1.90
OPEO36.13	4/4/1994	100	0.05
OPEO36.13	5/4/1994	300	0.84
OPEO36.13	5/9/1994	1,600	1.85
OPEO36.13	6/13/1994	500	0.01
OPEO36.13	7/5/1994	500	0.25
OPEO36.13	8/1/1994	900	0.52
OPEO36.13	9/1/1994	300	0.45
OPEO36.13	10/3/1994	500	0.13
OPEO36.13	11/8/1994	100	0.02
OPEO36.13	12/1/1994	700	0.80
OPEO36.13	1/3/1995	100	0.30
OPEO36.13	2/9/1995	100	0.01
OPEO36.13	3/2/1995	100	0.12
OPEO36.13	4/3/1995	700	0.00
OPEO36.13	6/5/1995	1,100	1.09
OPEO36.13	7/5/1995	700	0.70
OPEO36.13	8/1/1995	600	0.00
OPEO36.13	9/5/1995	1,400	0.00
OPEO36.13	10/16/1995	200	0.79
OPEO36.13	11/1/1995	500	0.32
OPEO36.13	12/20/1995	300	1.80
OPEO36.13	1/16/1996	2,700	0.40
OPEO36.13	2/1/1996	100	1.00
OPEO36.13	3/4/1996	100	0.00
OPEO36.13	4/1/1996	300	2.08
OPEO36.13	5/1/1996	100	0.97
OPEO36.13	7/1/1996	800	0.00
OPEO36.13	8/15/1996	500	3.10
OPEO36.13	9/4/1996	2,600	0.90
OPEO36.13	10/7/1996	500	0.00
OPEO36.13	11/20/1996	100	0.30
OPEO36.13	12/2/1996	3,200	1.30
OPEO36.13	1/2/1997	100	0.10
OPEO36.13	2/3/1997	100	0.00
OPEO36.13	3/4/1997	1,800	1.90
OPEO36.13	4/1/1997	100	0.60
OPEO36.13	5/19/1997	1,200	0.00
OPEO36.13	6/2/1997	3,500	2.50
OPEO36.13	7/7/1997	200	0.00
OPEO36.13	8/6/1997	300	1.40
OPEO36.13	9/3/1997	400	0.70

Table G. 3. Observed FC concentration and antecedent rainfall for Lower Opequon

Station	Date	cfu/100mL	Total Rainfall for sampling day and preceding 5 days (inches)
1AOPE025.10	7/1/1992	8,000	0.30
1AOPE025.10	8/4/1992	300	0.20
1AOPE025.10	9/16/1992	400	0.00
1AOPE025.10	1/13/1993	500	0.80
1AOPE025.10	3/3/1993	200	0.30
1AOPE025.10	5/4/1993	500	0.10
1AOPE025.10	6/10/1993	200	1.20
1AOPE025.10	7/1/1993	200	0.60
1AOPE025.10	9/14/1993	100	0.00
1AOPE025.10	10/4/1993	200	0.40
1AOPE025.10	12/1/1993	600	3.30
1AOPE025.10	1/3/1994	100	0.20
1AOPE025.10	4/4/1994	100	0.05
1AOPE025.10	5/4/1994	200	0.84
1AOPE025.10	5/9/1994	1,700	1.85
1AOPE025.10	6/13/1994	400	0.01
1AOPE025.10	7/5/1994	300	0.25
1AOPE025.10	8/1/1994	100	0.52
1AOPE025.10	9/1/1994	2,600	0.45
1AOPE025.10	10/3/1994	200	0.13
1AOPE025.10	6/5/1995	800	1.09
1AOPE025.10	7/5/1995	100	0.70
1AOPE025.10	8/1/1995	200	0.00
1AOPE025.10	9/5/1995	600	0.00
1AOPE025.10	10/16/1995	100	0.79
1AOPE025.10	11/1/1995	200	0.32
1AOPE025.10	12/20/1995	1,100	1.80
1AOPE025.10	2/1/1996	800	1.00
1AOPE025.10	4/1/1996	1,000	2.08
1AOPE025.10	5/1/1996	100	0.97
1AOPE025.10	7/1/1996	300	0.00
1AOPE025.10	8/15/1996	400	3.10
1AOPE025.10	9/4/1996	900	0.90
1AOPE025.10	10/7/1996	200	0.00
1AOPE025.10	11/20/1996	100	0.30
1AOPE025.10	12/2/1996	2,200	1.30
1AOPE025.10	1/2/1997	100	0.10
1AOPE025.10	3/4/1997	3,000	1.90
1AOPE025.10	5/19/1997	100	0.00
1AOPE025.10	6/2/1997	1,700	2.50

Appendix H
Required Reductions in Fecal Coliform Loads by Sub Watershed – Allocation Scenario

Table H. 1. Required annual reductions in nonpoint sources in sub watershed ABR-01 of the Abrams Creek watershed.

Source	Current Conditions load (x10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	3,848	0.06%	2,693	30%
Wildlife Direct Deposit	2,967	0.05%	2,967	0%
ILS	13,604	0.22%	680	95%
PLS	6,271,588	99.68%	6,266,855	0%
Total	6,292,007	--	6,273,195	--

Table H. 2. Required annual reductions in nonpoint sources in sub watershed ABR-02 of the Abrams Creek watershed.

Source	Current Conditions load (x10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	30%
Wildlife Direct Deposit	17,980	0.61%	17,980	0%
ILS	380,973	12.94%	19,049	95%
PLS	2,544,788	86.45%	1,612,261	37%
Total	2,943,742	--	1,649,290	--

Table H. 3. Required annual reductions in nonpoint sources in sub watershed ABR-03 of the Abrams Creek watershed.

Source	Current Conditions load (x10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	30%
Wildlife Direct Deposit	8,477	0.75%	8,477	0%
ILS	73,567	6.55%	3,678	95%
PLS	1,041,900	92.70%	751,570	28%
Total	1,123,944	--	763,726	--

Table H. 4. Required annual reductions in nonpoint sources in sub watershed ABR-04 of the Abrams Creek watershed.

Source	Current Conditions load ($x10^8$ cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($x10^8$ cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	30%
Wildlife Direct Deposit	8,655	0.59%	8,655	0%
ILS	44,747	3.03%	2,237	95%
PLS	1,421,698	96.38%	762,145	46%
Total	1,475,100	--	773,037	--

Table H. 5. Required annual reductions in nonpoint sources in sub watershed ABR-05 of the Abrams Creek watershed.

Source	Current Conditions load ($x10^8$ cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($x10^8$ cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	30%
Wildlife Direct Deposit	4,553	0.48%	4,553	0%
ILS	18,286	1.93%	914	95%
PLS	926,855	97.60%	418,777	55%
Total	949,694	--	424,245	--

Table H. 6. Required annual reductions in nonpoint sources in sub watershed ABR-06 of the Abrams Creek watershed.

Source	Current Conditions load ($x10^8$ cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($x10^8$ cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	30%
Wildlife Direct Deposit	11,467	0.21%	11,467	0%
ILS	764,285	14.32%	38,214	95%
PLS	4,561,016	85.46%	1,155,951	75%
Total	5,336,768	--	1,205,632	--

Table H. 7. **Required annual reductions in nonpoint sources in sub watershed ABR-07 of the Abrams Creek watershed.**

Source	Current Conditions load ($x10^8$ cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($x10^8$ cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	30%
Wildlife Direct Deposit	18,827	0.27%	18,827	0%
ILS	805,558	11.46%	40,278	95%
PLS	6,207,946	88.28%	1,805,661	71%
Total	7,032,332	--	1,864,767	--

Table H. 8. **Required annual reductions in nonpoint sources in sub watershed ABR-08 of the Abrams Creek watershed.**

Source	Current Conditions load ($x10^8$ cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($x10^8$ cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	30%
Wildlife Direct Deposit	8,344	0.11%	8,344	0%
ILS	1,018,922	13.08%	50,946	95%
PLS	6,760,083	86.81%	1,021,333	85%
Total	7,787,349	--	1,080,623	--

Table H. 9. **Required annual reductions in nonpoint sources in sub watershed ABR-09 of the Abrams Creek watershed.**

Source	Current Conditions load ($x10^8$ cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($x10^8$ cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	30%
Wildlife Direct Deposit	15,663	0.18%	15,663	0%
ILS	1,669,496	19.67%	83,475	95%
PLS	6,803,076	80.15%	1,678,121	75%
Total	8,488,235	--	1,777,259	--

Table H. 10. Required annual reductions in nonpoint sources in sub watershed ABR-10 of the Abrams Creek watershed.

Source	Current Conditions load (x10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL direct nonpoint source allocation load (x10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	26,918	0.06%	18842	30%
Wildlife Direct Deposit	17,730	0.04%	17,730	0%
ILS	460,142	1.06%	23,007	95%
PLS	42,981,487	98.84%	41,683,838	0%
Total	43,486,276	--	41,743,417	--

Table H. 11. Required annual reductions in nonpoint sources in sub watershed ABR-11 of the Abrams Creek watershed.

Source	Current Conditions load (x10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	9,717	0.11%	6,802	30%
Wildlife Direct Deposit	12,344	0.14%	12,344	0%
ILS	425,206	4.71%	21,260	95%
PLS	8,582,086	95.05%	7,216,940	0%
Total	9,029,354	--	7,257,346	--

Table H. 12. Required annual reductions in nonpoint sources in sub watershed B08-01 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	526	1.01%	26	95%
ILS	235	0.45%	117	50%
PLS	51,197	98.54%	22,970	55%
Total	51,958			--

Table H. 13. Required annual reductions in nonpoint sources in sub watershed B08-02 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	2,583	1.06%	0	100%
ILS	374	0.15%	187	50%
PLS	239,767	98.78%	5,830	98%
Total	242,725	--		--

Table H. 14. Required annual reductions in nonpoint sources in sub watershed B08-03 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	5,461	0.45%	0	100%
ILS	1,005	0.08%	503	50%

PLS	1,201,250	99.46%	97,341	92%
Total	1,207,716	--		--

Table H. 15. Required annual reductions in nonpoint sources in sub watershed B08-04 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	1,951	1.90%	0	100%
ILS	14	0.01%	7	50%
PLS	100,488	98.08%	10,665	89%
Total	102,452	--		--

Table H. 16. Required annual reductions in nonpoint sources in sub watershed B08-05 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	5,765	0.71%	0	100%
ILS	269	0.03%	134	50%
PLS	806,140	99.26%	50,679	94%
Total	812,174	--		--

Table H. 17. Required annual reductions in nonpoint sources in sub watershed B08-06 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	6,945	0.18%	0	100%

ILS	646	0.02%	323	50%
PLS	3,946,262	99.81%	363,186	91%
Total	3,953,853	--		--

Table H. 18. Required annual reductions in nonpoint sources in sub watershed B08-07 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	6,829	0.50%	0	100%
ILS	7,218	0.53%	3,609	50%
PLS	1,358,115	98.98%	109,011	92%
Total	1,372,163	--		--

Table H. 19. Required annual reductions in nonpoint sources in sub watershed B08-08 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	6,994	1.09%	0	100%
ILS	1,626	0.25%	813	50%
PLS	630,143	98.65%	36,320	94%
Total	638,763	--		--

Table H. 20. Required annual reductions in nonpoint sources in sub watershed B08-09 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	110,434	0.63%	0	100%
Wildlife Direct Deposit	11,880	0.07%	0	100%
ILS	10,800	0.06%	5,400	50%

PLS	17,457,441	99.24%	1,698,224	90%
Total	17,590,555	--		--

Table H. 21. Required annual reductions in nonpoint sources in sub watershed B08-10 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	88,347	0.53%	0	100%
Wildlife Direct Deposit	16,249	0.10%	0	100%
ILS	1,043	0.01%	521	50%
PLS	16,709,896	99.37%	1,303,042	92%
Total	16,815,535	--		--

Table H. 22. Required annual reductions in nonpoint sources in sub watershed B08-11 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	6,775	0.95%	0	100%
ILS	659	0.09%	330	50%
PLS	706,735	98.96%	50,331	93%
Total	714,168	--		--

Table H. 23.Required annual reductions in nonpoint sources in sub watershed B08-12 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%

Wildlife Direct Deposit	15,416	0.28%	0	100%
ILS	4,023	0.07%	2,012	50%
PLS	5,496,178	99.65%	486,744	91%
Total	5,515,618	--		--

Table H. 24. Required annual reductions in nonpoint sources in sub watershed B08-13 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	17,500	0.47%	0	100%
ILS	10,959	0.30%	5,479	50%
PLS	3,672,358	99.23%	288,869	92%
Total	3,700,817	--		--

Table H. 25. Required annual reductions in nonpoint sources in sub watershed B08-14 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	100%
Wildlife Direct Deposit	6,915	0.24%	0	100%
ILS	3,784	0.13%	1,892	50%
PLS	2,893,492	99.63%	254,316	91%
Total	2,904,191	--		--

Table H. 26. Required annual reductions in nonpoint sources in sub watershed B08-15 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	368,421	0.65%	0	100%

Wildlife Direct Deposit	8,024	0.01%	0	100%
ILS	1,602	0.00%	801	50%
PLS	56,005,003	99.33%	5,557,117	90%
Total	56,383,050	--		--

Table H. 27. Required annual reductions in nonpoint sources in sub watershed B08-16 of the Upper Opequon Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	368,705	0.67%	0	100%
Wildlife Direct Deposit	11,811	0.02%	0	100%
ILS	2,708	0.00%	1,354	50%
PLS	54,463,543	99.30%	5,381,770	90%
Total	54,846,767	--		--

Table H. 28. Required annual reductions in nonpoint sources in subwatershed B09-1 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	23,805	0.06%	23,805	0%
Wildlife Direct Deposit	22,829	0.05%	22,829	0%
ILS	1,283	0.00%	436	66%
PLS	42,121,241	99.89%	2,915,291	93%
Total	42,169,157	--	2,962,361	--

Table H. 29. Required annual reductions in nonpoint sources in subwatershed B09-2 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	7,108	1.08%	7,108	0%
ILS	69	0.01%	23.5	66%
PLS	652,221	98.91%	331,470	49%
Total	659,398	--	338,602	--

Table H. 30. Required annual reductions in nonpoint sources in subwatershed B09-3 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction

Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	11,189	0.77%	11,189	0%
ILS	100	0.01%	34.2	66%
PLS	1,434,853	99.22%	578,214	60%
Total	1,446,142	--	589,437	--

Table H. 31. Required annual reductions in nonpoint sources in subwatershed B09-4 of the Lower Opequon Watershed Remnant.

Source	**Current Conditions load (x 10^8 cfu/year)**	**Percent of total load to stream from nonpoint sources**	**TMDL nonpoint source allocation load (x 10^8 cfu/year)**	**Percent reduction**
Cattle Direct Deposit	55,611	0.07%	55,611	0%
Wildlife Direct Deposit	6,110	0.01%	6,110	0%
ILS	92	0.00%	31.3	66%
PLS	82,803,558	99.93%	4,383,044	95%
Total	82,865,371	--	4,444,796	--

Table H. 32. Required annual reductions in nonpoint sources in subwatershed B09-5 of the Lower Opequon Watershed Remnant.

Source	**Current Conditions load (x 10^8 cfu/year)**	**Percent of total load to stream from nonpoint sources**	**TMDL nonpoint source allocation load (x 10^8 cfu/year)**	**Percent reduction**
Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	11,370	1.02%	11,370	0%
ILS	610	0.05%	207	66%
PLS	1,101,457	98.92%	486,439	56%
Total	1,113,437	--	498,016	--

Table H. 33. Required annual reductions in nonpoint sources in subwatershed B09-6 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	39,567	0.06%	39,567	0%
Wildlife Direct Deposit	16,925	0.03%	16,925	0%
ILS	9,792	0.02%	3,329	66%
PLS	63,244,443	99.90%	3,405,599	95%
Total	63,310,727	--	3,465,420	--

Table H. 34. Required annual reductions in nonpoint sources in subwatershed B09-7 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	11,700	0.82%	11,700	0%
ILS	377	0.03%	128	66%
PLS	1,410,294	99.15%	559,592	60%
Total	1,422,371	--	571,420	--

Table H. 35. Required annual reductions in nonpoint sources in subwatershed B09-8 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	9,975	0.09%	9,975	0%
Wildlife Direct Deposit	20,643	0.18%	20,643	0%
ILS	3,943	0.03%	1,340	66%
PLS	11,440,941	99.70%	1,336,691	88%
Total	11,475,501	--	1,368,650	--

Table H. 36. Required annual reductions in nonpoint sources in subwatershed B09-9 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	9,587	0.53%	9,587	0%
ILS	1,306	0.07%	444	66%
PLS	1,791,754	99.40%	621,272	65%
Total	1,802,647	--	631,303	--

Table H. 37. Required annual reductions in nonpoint sources in subwatershed B09-10 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	13,164	1.04%	13,164	0%
ILS	832	0.07%	283	66%
PLS	1,253,521	98.90%	562,662	55%
Total	1,267,517	--	576,110	--

Table H. 38. Required annual reductions in nonpoint sources in subwatershed B09-11 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	33,130	0.10%	33,130	0%
Wildlife Direct Deposit	25,888	0.08%	25,888	0%
ILS	2,276	0.01%	774	66%
PLS	33,218,236	99.82%	2,806,488	92%
Total	33,279,530	--	2,866,279	--

Table H. 39. Required annual reductions in nonpoint sources in subwatershed B09-12 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	1,953	1.37%	1,953	0%
ILS	152	0.11%	51.8	66%
PLS	140,363	98.52%	69,180	51%
Total	142,469	--	71,185	--

Table H. 40. Required annual reductions in nonpoint sources in subwatershed B09-13 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	19,285	0.58%	19,285	0%
ILS	77,980	2.34%	26,513	66%
PLS	3,234,722	97.08%	1,189,098	63%
Total	3,331,987	--	1,234,897	--

Table H. 41. Required annual reductions in nonpoint sources in subwatershed B09-14 of the Lower Opequon Watershed Remnant.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle Direct Deposit	0	0.00%	0	0%
Wildlife Direct Deposit	1,391	1.78%	1,391	0%
ILS	7	0.01%	2.5	66%
PLS	76,752	98.21%	42,289	45%
Total	78,149	--	43,682	--

Appendix I
Capping Procedure Used In Modeling of Upper Opequon Creek

While simulating the hydrology and water quality in the Upper Opequon Creek watershed, the model produced very low stages (<0.2 ft) that resulted in extremely high fecal coliform concentrations that are not in the observed record. Some simulated concentrations were in excess of 1.1×10^6. The simulation process and model capabilities are limited at these low stage levels. At stages greater than approximately 0.2 ft, the model performs well. To compensate for the concentrations that corresponded to extremely low stages, a filtering technique was employed.

Given the following definitions

S_i = the depth of water in the stream channel (feet),

C_i = in-stream simulated fecal coliform concentration (cfu/100mL),

SCR_i = stage vs. concentration ratio for a pair of simulated stage and concentration values (cfu/100mL per ft),

i = a counter to identify a given pair of values in an array,

Cap = the maximum fecal coliform concentration allowed (8,000 cfu/100mL),

S_T = stage threshold value (0.167 ft),

CRT = Cap Ratio Threshold

= 8,000 cfu/100mL ÷ 0.167 ft

≈ 48,000 (cfu/100mL per ft)

In the filter procedure, if the SCR_i is equal to or greater than the CRT, then the corresponding fecal coliform concentration C_i is set to the Cap value of 8,000 cfu/100mL. If the SCR_i is less than the CRT, the simulated concentration is unchanged.

Algorithm:

Let CRT = 8,000 cfu/100mL ÷ 0.167 ft ≈ 48,000 (cfu/100mL per ft)

If	$SCR_i = C_i/S_i \geq CRT$	then	C_i = 8,000 cfu/100mL
Else if	SCRi < 48,000	then	$C_i = SCR_i \times S_i$

Appendix J.
Scenarios for Tenfold Increase in Permitted Discharge Flows

To allow for future growth, scenarios were created for the Upper and Lower Opequon watersheds in which the point source flows were increased by a factor of 10, while retaining the 200 cfu/100 mL limit on bacteria. This effectively increased the WLA by a factor of 10. No scenarios were generated for the Abrams Creek watershed because it had no permitted dischargers of bacteria that had permitted flows. Figures J.1 and J.2 display the results for Upper and Lower Opequon Creeks, respectively. The TMDL equations that would represent these situations are included in Table J.1.

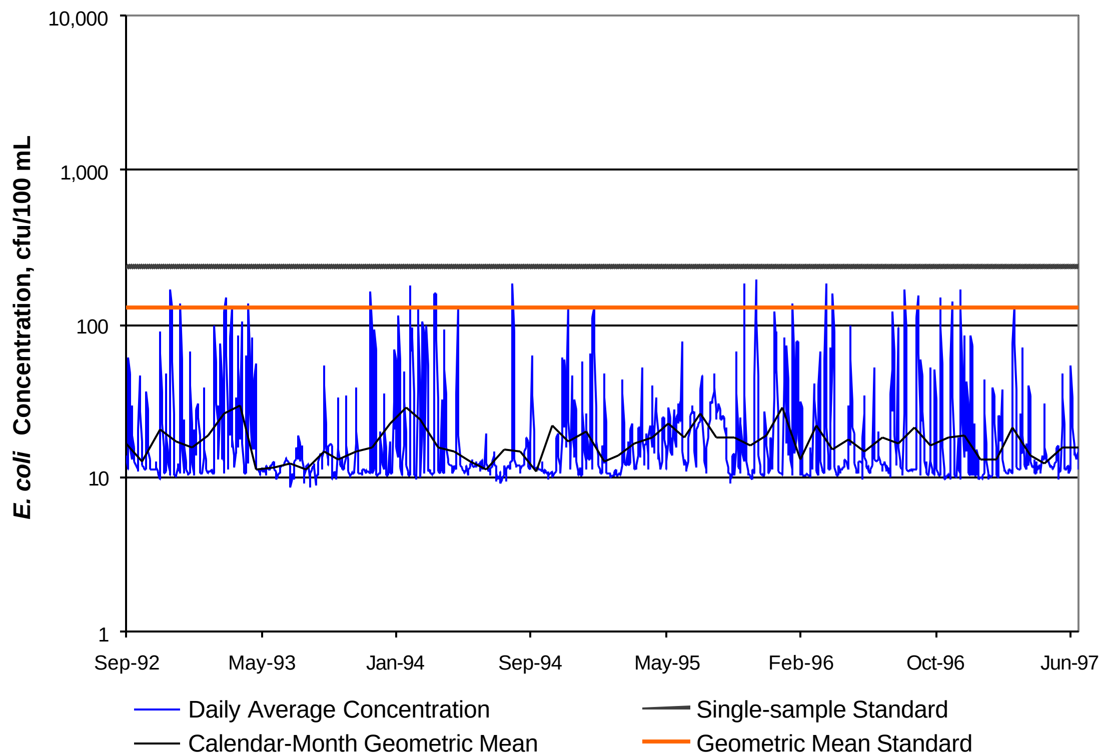

Figure J.1. Daily average and calendar-month geometric mean *E. coli* concentration in the Upper Opequon watershed under the tenfold WLA increase scenario.

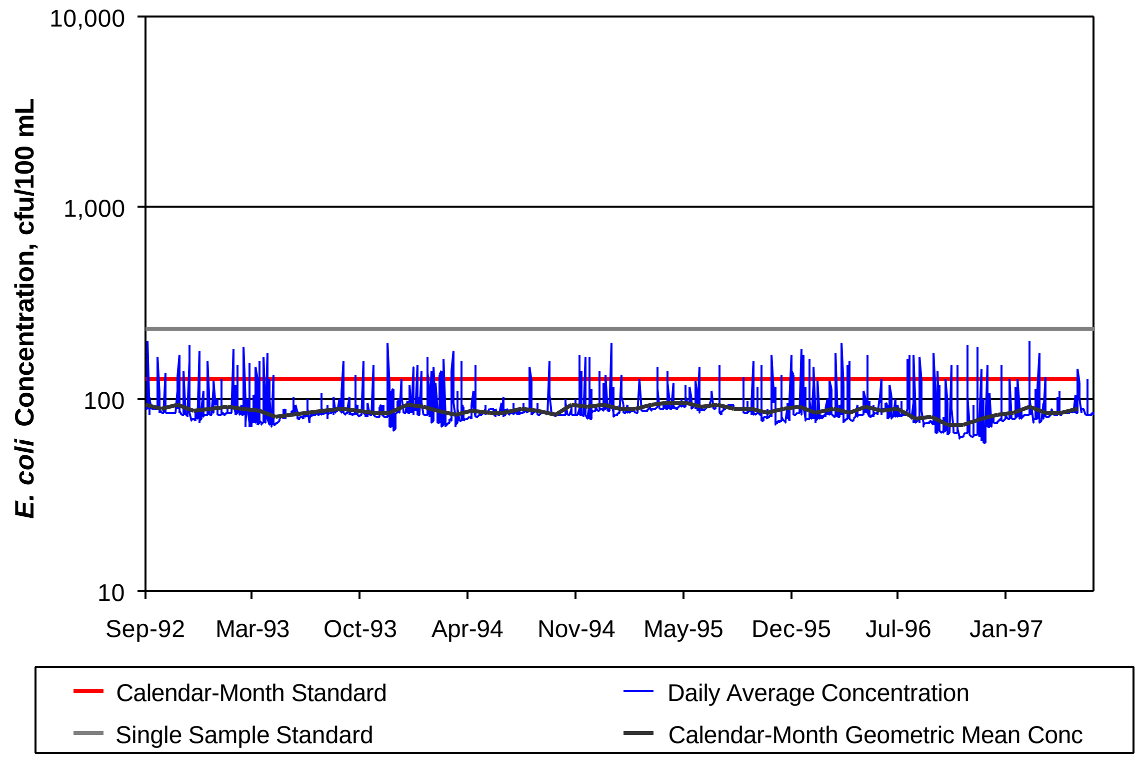

Figure J.2. Daily average and calendar-month geometric mean *E. coli* concentration in the Lower Opequon watershed under the tenfold WLA increase scenario.

Table J.1. Average annual *E. coli* loadings (cfu/year) at the watershed outlet for the Upper and Lower Opequon watersheds under the tenfold WLA increase scenario.

Watershed	SWLA	SLA	TMDL
Upper Opequon	$3,577 \times 10^{10}$	$3,636.7 \times 10^{10}$	$7,213.7 \times 10^{10}$
Lower Opequon Remnant	$2,130 \times 10^{11}$	948.1×10^{11}	$3,078.1 \times 10^{11}$

As can be seen from the graphs, the new scenarios result in no violations of the instantaneous or geometric mean standards. Therefore, it is assumed that future growth in point source dischargers with a consistent permitted bacteria concentration of 200 cfu/100 mL fecal coliform will not cause additional violations of the water quality standards.